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ICAR Sponsored Winter School on  
**Climate change impacts  
and resilience options  
for Indian marine fisheries**

**08 - 29 November, 2018**

# Course Manual



Indian Council of Agricultural Research  
**Central Marine Fisheries Research Institute**  
Post Box No. 1603, Ernakulam North P.O., Kochi-682 018  
Kerala, India



*CMFRI Training Manual Series No. 18/2018*

Course Manual - Winter School on

# **Climate change impacts and resilience options for Indian marine fisheries**

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ICAR-Central Marine Fisheries Research Institute  
Post Box No. 1603, Ernakulam North P.O, Kochi - 682 018





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# Climate change impacts and resilience options for Indian marine fisheries

ICAR-Central Marine Fisheries Research Institute | 8<sup>th</sup>-29<sup>th</sup> November 2018

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# Foreword



Indian marine fisheries, in recent years, have been at the receiving end from the impacts of climate change. ICAR-CMFRI has been at the forefront of research programs addressing climate change issues on marine fisheries, and CMFRI scientists first participated in a national network program on climate change way back in 2004. The work done under this project revealed alterations in fish biology due to climate variability and changes in the phenological aspects of marine fishes with variability recorded in environmental conditions. The initial years of research on climate change were focused on understanding such changes. However, over time, the focus of such research programs has begun to shift to adaptation and mitigation options of climate change in marine fisheries.

Research on vulnerability of marine fisheries resources, life cycle analysis and related research areas were augmented under these thrust areas. Resilient products, strategies and innovations were adopted in the last decade to involve the society and stakeholders in the development of mitigation options. Efforts have also been made to devise new strategies to counter issues related to climate change on marine ecosystems and resources. With the advent of diverse technologies in operational fields such as satellite remote sensing, numerical modelling and observational research, insight into the impacts of climate change on marine fisheries across the world has deepened.

In recent years, efforts have been undertaken to predict climate variability under different RCP scenarios which will be useful for forecasting the long term impacts of climate change. Forecasts such as these will enable policy planners to develop action plans on climate change at the local, regional and national levels. In order to

ensure successful execution of this, there is a pressing need for scientists who have trained in the development and interpretation of such models, as well as those who understand the long and short-term ramifications of climate change. I am happy that the NICRA team of ICAR-CMFRI took this initiative in the form of organizing an ICAR funded winter school to develop human resources in climate change related aspects. The course is well designed, covering multiple disciplines and benefitting general as well as specialised audience. I hope that the efforts of ICAR-CMFRI will be fruitful in producing academicians and researchers who are ready to lead and resolve climate change related challenges faced by fisheries on completion of this course.

I take this opportunity to congratulate Dr. P.U. Zacharia and the team for this well-structured winter school.

A. Gopalakrishnan  
Director, ICAR-CMFRI

# Preface



Climate change is one of, if not the most significant issue faced by mankind today and nowhere else are the effects of climate change and global warming seen more clearly than in marine fisheries today. Climate change affects the marine fishery sector in every possible way – from the resources it revolves around, to the people who harvest them. In India alone, the fisheries sector employs over two million people directly and indirectly, and the country is ranked among the top 10 fish producing countries in the world. The total marine annual fish landing now amounts to 3.87 million tonnes, which contributes significantly to socio-economic development of coastal populations. It is estimated that the economic losses due to climate change in India alone may amount to as much as 1.5 million crore rupees and the loss of a potential source of food security may have further downstream effects on the Indian economy.

Climate change has also been predicted to affect the most vulnerable sections of society including subsistence and artisanal fishers, and members of the fisher folk community living in coastal and nearshore areas. The asymmetrical effects of climate change, especially when considering the inherently low emissions of the Indian fishing sector, further highlight the need for targeted programs that promote adaptation and resilience strategies among these communities.

Extreme weather events resulting from climate change and fisheries have greatly increased in frequency over the past few years, causing widespread destruction, and drops in productivity in the fishing industry, particularly in light of India's long and densely populated coastline. The warming of waters is predicted to cause significant upheaval in the fishery industry – through ocean acidification, extension and shifts in migration boundaries and physiological changes occurring in common stock species. The widespread bleaching of corals also poses a significant risk to the habitats of many marine species.

The study of climate change is an inherently multidisciplinary one. The course was therefore designed keeping that in mind, seeking to educate the participants, who hailed from a variety of fields, on the far reaching effects and consequences of global warming and climate change on the fisheries sector. By covering a wide array of critical information regarding climate change and its impacts - methods for measuring vulnerability of key species, coastal zone management, Integrated Multi Trophic Aquaculture, statistical methods for assessing climate change impacts, blue carbon, methods for fish biology and many more, participants in this Winter School are now poised to continue research and study in the increasingly field of climate change and global warming with the lessons they have learned here.

This book represents a collection of the many enlightening lectures delivered by well-regarded resource persons, both internal and external, to the participants over the course of the program.

P.U. Zacharia  
Course Director

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P.U. Zacharia, R.G. Ninan and G.Rojith

ICAR -Central Marine Fisheries Research Institute, Kochi

## Introduction

### Global Warming

Global warming is a long-term rise in the average temperature of the Earth's climate system, an aspect of climate change shown by temperature measurements and by multiple effects of the warming. The term commonly refers to the mainly human-caused observed warming since pre-industrial times and its projected continuation, though there were also much earlier periods of global warming. In the modern context the terms are commonly used interchangeably, but *global warming* more specifically relates to worldwide surface temperature increases; while *climate change* is any regional or global statistically identifiable persistent change in the state of climate which lasts for decades or longer, including warming or cooling. Many of the observed warming changes since the 1950s are unprecedented in the instrumental temperature record and in historical and paleoclimate proxy records of climate change over thousands to millions of years.

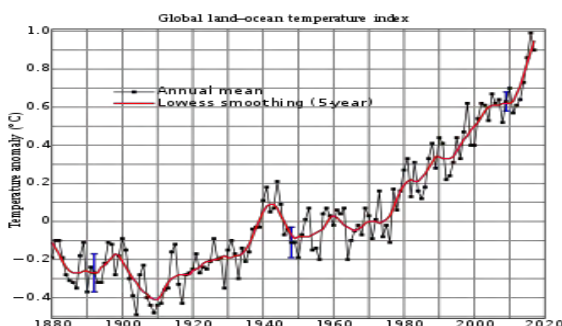


Figure 1: Global mean surface-temperature change from 1880 to 2017, relative to the 1951–1980 mean.

Global mean surface-temperature change from 1880 to 2017, relative to the 1951–1980 mean. The 1951–1980 mean is 14.19 °C (57.54 °F). The black line is the global annual mean, and the red line is the five-year local regression line. The blue uncertainty bars show a 95% confidence interval.

### **Reasons behind Global Warming**

The major cause of present global warming has been attributed to anthropogenic contribution to Greenhouse effect expansion through trapping the radiating heat from atmosphere. Water vapour, carbon dioxide, Methane, Nitrous oxide and Chloroflurocarbons (CFCs) are major gases that contribute to green house effect. Release of these gases to atmosphere happens through natural process such as hydrological cycles, volcanic eruptions and decomposition process or through human activities such as burning of fossil fuels, agricultural practices and industrial process.

Intergovernmental Panel on Climate Change (IPCC) through its Fifth Assessment Report emphasis that probability more than 95 % of earth's warming is through human activities during past five decades. However there are a group of scientists who claims that the climate change could be a result of natural solar process change. But the climate models that include solar irradiance could not reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.

### **Proof for scientific inferences on Climate Change**

IPCC states that scientific evidence for warming of climate system is unequivocal. The heat trapping nature of carbon dioxide and other gases were demonstrated in the mid of 19th century. Anthropogenic activities since the mid-20th century have been attributed as cause for global warming and were observed to increase thereafter. Indications for climate change have been derived from data collected through earth-orbiting satellites. Ice cores samples from Greenland, Antarctica and tropical mountain glaciers indicate earth's climate response to greenhouse gas concentrations. Paleoclimatic evidences found in tree rings, ocean sediments, coral reefs and layers of sedimentary rocks indicates that current warming is occurring around 10 times faster than average rate of ice age recovery warming (NRC, 2006). NASA is an expert in climate and Earth science. While its role is not to set climate policy or prescribe particular responses or solutions to climate change, its purview does include providing the robust scientific data needed to understand climate change and evaluating the impact of efforts to combat it.

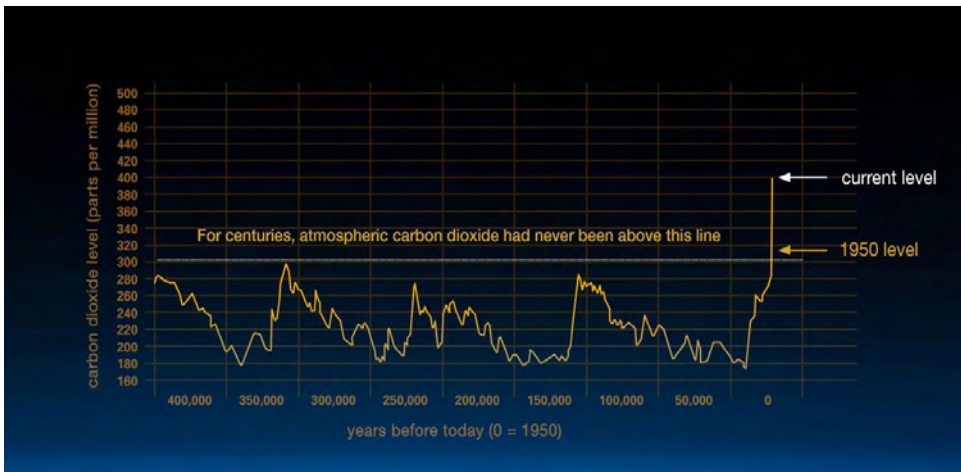


Figure 2. This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO<sub>2</sub> has increased since the Industrial Revolution. (Credit: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO<sub>2</sub> record.)

NASA then makes this information available to the global community – the public, policy- and decision-makers and scientific and planning agencies around the world. The compelling evidences for rapid climate change as per NASA are as listed below.

- Global temperature rise since late 19<sup>th</sup> century
- Ocean warming since 1926
- Sea level rise (8 inches in last century)
- Declining Arctic sea ice (extent and thickness over last several decades)
- Shrinking ice sheets (loss around 281 billion tons of ice per year at Greenland and loss around 119 billion tons at Antarctica between 1993 and 2016)
- Glacial retreats (Alps, Himalayas, Andes, Rockies, Alaska and Africa)
- Decrease in snow cover (Northern hemisphere in past five decades)
- Extreme events (Increase in high temperature events, decrease in low temperature events since 1950 and increase in intense rainfall events)

NASA reports future climate change effects as listed below:

- Change will continue through this century and beyond
- Temperatures will continue to rise
- Frost-free season (and growing season) will lengthen
- Changes in precipitation patterns

- More droughts and heat waves
- Arctic likely to become ice-free
- Hurricanes will become stronger and more intense
- Sea level will rise 1-4 feet by 2100

The following selected resources from U.S. government organizations provide information about options for responding to climate change.

- Climate Data Initiative
- U.S. Climate Resilience Toolkit
- National Oceanic and Atmospheric Administration
- National Climate Assessment 2014
- U.S. Department of Energy
- Environmental Protection Agency
- State of California's Climate Change Portal
- U.N. Framework on Climate Change

### **The Intergovernmental Panel on Climate Change (IPCC)**

IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. 195 countries are now Members of the IPCC. IPCC reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. So far significant Assessment Reports (AR) were published as 1<sup>st</sup> AR on 1990 (lead to UNFCCC formation), 2<sup>nd</sup> AR on 1995 (lead to adoption of Kyoto protocol), 3<sup>rd</sup> AR on 2001, **4<sup>th</sup> AR on 2007 (led to Nobel Peace Prize)**, 5<sup>th</sup> AR as 4 parts in 2013 and 2014, while 6<sup>th</sup> AR is expected on 2022.

IPCC also prepares and publishes Special Reports, Methodology Reports, Technical papers and Supporting Material. The Nobel Peace Prize 2007 was awarded jointly to Intergovernmental Panel on Climate Change (IPCC) and Albert Arnold (Al) Gore Jr. "for their efforts to build up and disseminate greater knowledge about man-made climate change and to lay the foundations for the measures that are needed to counteract such change". The COP of UNFCCC receives the outputs of the IPCC and uses IPCC data and information as a baseline on the state of knowledge on climate change in making science based decisions.

### **Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)**

IPCC decided to prepare a special report on climate change and the oceans and the cryosphere. During its 45th Session, the Panel approved the outline of the *Special Report on the Ocean and Cryosphere in a Changing Climate* to be finalized in September 2019.

COP21 of the United Nations Framework Convention on Climate Change held in Paris on 2015 featured the role of oceans, inland waters and aquatic ecosystems for temperature regulation and carbon sequestration, and highlighted the urgency of reversing the current trend of overexploitation and pollution to restore aquatic ecosystem services and the productive capacity of the oceans. Consequently Food and Agriculture Organization of the United Nations released the much esteemed publication 'State of world fisheries and aquaculture, 2016' which acknowledges India as among the major producers of aquatic animals from aquaculture.

### **Findings of the Fifth Assessment Report**

In 2013, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded, "It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century." The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. In view of the dominant role of human activity in causing it, the phenomenon is sometimes called "*anthropogenic* global warming" or "*anthropogenic* climate change".

Climate model projections summarized in the report indicated that during the 21st century, the global surface temperature is likely to rise a further 0.3 to 1.7 °C to 2.6 to 4.8 °C depending on the rate of greenhouse gas emissions.

Future climate change and associated impacts will differ from region to region. Anticipated effects include rising sea levels, changing precipitation, and expansion of deserts in the subtropics. Warming is expected to be greater over land than over the oceans and greatest in the Arctic, with the continuing retreat of glaciers, permafrost, and sea ice.

Other likely changes include more frequent extreme weather events such as heat waves, droughts, wildfires, heavy rainfall with floods, and heavy snowfall; ocean acidification; and species extinctions due to shifting temperature regimes. Effects significant to humans include the threat to food security from decreasing crop yields and the abandonment of populated

areas due to rising sea levels. Because the climate system has a large "inertia" and greenhouse gases will remain in the atmosphere for a long time, many of these effects will persist for not only decades or centuries, but tens of thousands of years. Possible societal responses to global warming include mitigation by emissions reduction, adaptation to its effects, building systems resilient to its effects, and possible future climate engineering.

Most countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC), whose ultimate objective is to prevent dangerous anthropogenic climate change. Parties to the UNFCCC have agreed that deep cuts in emissions are required and that global warming should be limited to well below 2.0 °C compared to pre-industrial levels, with efforts made to limit warming to 1.5 °C. Some scientists call into question climate adaptation feasibility, with higher emissions scenarios, or the two degree temperature target.

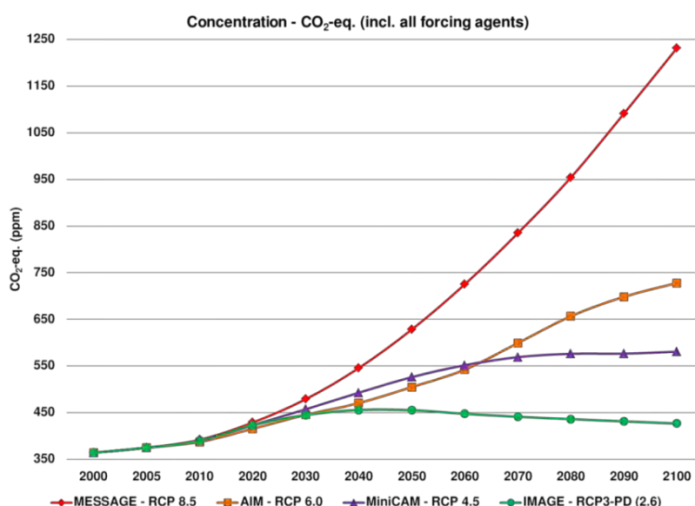


Figure 3. Future CO<sub>2</sub> projections, including all forcing agents' atmospheric CO<sub>2</sub>-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to four RCPs (Representative Concentration Pathways)

## History of climate change

The history of climate change science began in the early 19th century when ice ages and other natural changes in paleoclimate were first suspected and the natural greenhouse effect first identified. In the late 19th century, scientists first argued that human emissions of greenhouse gases could change the climate. In the 1960s, the warming effect of carbon dioxide gas became increasingly



convincing. By the 1990s, greenhouse gases were acknowledged to be deeply involved in most climate changes and human caused emissions were bringing discernible global warming.

Since the 1990s, scientific research on climate change has included multiple disciplines and has expanded. Research during this period has been summarized in the Assessment Reports by the Intergovernmental Panel on Climate Change.

### Observed Temperature Changes

By itself, the climate system may generate random changes in global temperatures for years to decades at a time, but long-term changes emanate only from so-called *external forcings*. Examples of external forcings include changes in the composition of the atmosphere (e.g., increased concentrations of greenhouse gases), solar luminosity, volcanic eruptions, and variations in Earth's orbit around the Sun.

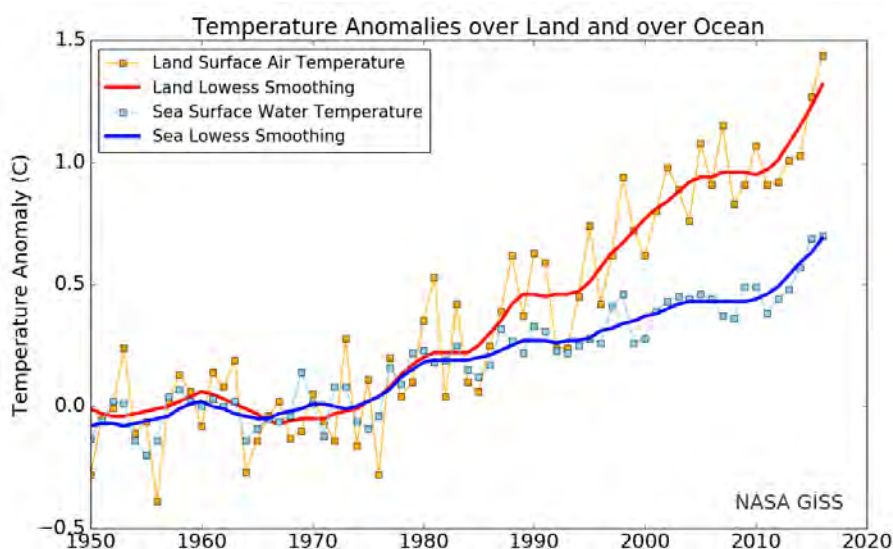


Figure 4. Annual (thin lines) and five-year lowess smooth (thick lines) for the temperature anomalies averaged over the Earth's land area (red line) and sea surface temperature anomalies (blue line) averaged over the part of the ocean that is free of ice at all times (open ocean).

### Greenhouse gases

On Earth, an atmosphere containing naturally occurring amounts of greenhouse gases causes air temperature near the surface to be warmer by about 33 °C than it

would be in their absence. Without the Earth's atmosphere, the Earth's average temperature would be well below the freezing temperature of water. The major greenhouse gases are water vapour, which causes about 36-70% of the greenhouse effect; carbon dioxide (CO<sub>2</sub>), which causes 9-26%; methane (CH<sub>4</sub>), which causes 4-9%; and ozone (O<sub>3</sub>), which causes 3-7%.

The greenhouse effect is the process by which absorption and emission of infrared radiation by gases in a planet's atmosphere warm its lower atmosphere and surface. It was proposed by Joseph Fourier in 1824, discovered in 1860 by John Tyndall, was first investigated quantitatively by Svante Arrhenius in 1896, and the hypothesis was reported in the popular press as early as 1912.

Human activity since the Industrial Revolution has increased the amount of greenhouse gases in the atmosphere, leading to increased radiative forcing from CO<sub>2</sub>, methane, tropospheric ozone, CFCs, and nitrous oxide. According to work published in 2007, the concentrations of CO<sub>2</sub> and methane had increased by 36% and 148% respectively since 1750. These levels are much higher than at any time during the last 800,000 years, the period for which reliable data has been extracted from ice cores. Less direct geological evidence indicates that CO<sub>2</sub> values higher than this were last seen about 20 million years ago.

Fossil fuel burning has produced about three-quarters of the increase in CO<sub>2</sub> from human activity over the past 20 years. The rest of this increase is caused mostly by changes in land-use, particularly deforestation. Estimates of global CO<sub>2</sub> emissions in 2011 from fossil fuel combustion, including cement production and gas flaring, was 34.8 billion tonnes (9.5 ± 0.5 PgC), an increase of 54% above emissions in 1990. Coal burning was responsible for 43% of the total emissions, oil 34%, gas 18%, cement 4.9% and gas flaring 0.7%.

In May 2013, it was reported that readings for CO<sub>2</sub> taken at the world's primary benchmark site in Mauna Loa surpassed 400 ppm. Monthly global CO<sub>2</sub> concentrations exceeded 400 ppm in March 2015, probably for the first time in several million years. On 12 November 2015, NASA scientists reported that human-made carbon dioxide continues to increase above levels not seen in hundreds of thousands of years; currently, about half of the carbon dioxide released from the burning of fossil fuels is not absorbed by vegetation and the oceans and remains in the atmosphere.

Emissions scenarios, estimates of changes in future emission levels of greenhouse gases, have been projected that depend upon uncertain economic, sociological, technological, and natural developments. In most scenarios, emissions continue to rise over the century, while in a few, emissions are reduced. Fossil fuel reserves are abundant, and will not limit carbon emissions in the 21st century. Emission scenarios, combined with modelling of the carbon cycle, have been used to produce estimates of how atmospheric concentrations of greenhouse gases might change in the future.

By itself, the climate system may generate random changes in global temperatures for years to decades at a time, but long-term changes emanate only from so-called *external forcings*. These forcings are "external" to the climate system, but not necessarily external to Earth. Examples of external forcings include changes in the composition of the atmosphere (e.g., increased concentrations of greenhouse gases), solar luminosity, volcanic eruptions, and variations in Earth's orbit around the Sun.

### **Environmental Effects**

The environmental effects of global warming are broad and far reaching, including:

- Arctic sea ice decline, sea level rise, retreat of glaciers: Global warming has led to decades of shrinking and thinning in a warm climate that has put the Arctic sea ice in a precarious position, it is now vulnerable to atmospheric anomalies. Recent projections suggest that Arctic summers could be ice-free (defined as ice extent less than 1 million square km) as early as 2025–2030. The sea level rise since 1993 has been estimated to have been on average 2.6 mm and 2.9 mm per year  $\pm$  0.4 mm. Additionally, sea level rise has accelerated from 1995 to 2015. Over the 21st century, the IPCC projects for a high emissions scenario, that global mean sea level could rise by 52–98 cm.
- Extreme weather, extreme events, tropical cyclones: Data analysis of extreme events from 1960 until 2010 suggests that droughts and heat waves appear simultaneously with increased frequency. Extremely wet or dry events within the monsoon period have increased since 1980. Projections suggest a probable increase in the frequency and severity of some extreme weather events, such as heat waves.
- Ecosystem changes, changes in ocean properties: In terrestrial ecosystems, the earlier timing of spring events, as well as poleward and upward shifts in plant and animal ranges, have been linked with high confidence to recent

warming. It is expected that most ecosystems will be affected by higher atmospheric CO<sub>2</sub> levels, combined with higher global temperatures. The physical effects of global warming on oceans include an increase in acidity, and a reduction of oxygen levels (ocean deoxygenation). Increases in atmospheric CO<sub>2</sub> concentrations have led to an increase in dissolved CO<sub>2</sub> and thus ocean acidity, measured by lower pH values. Ocean acidification threatens damage to coral reefs, fisheries, protected species, and other natural resources of value to society.

- Long-term effects of global warming, runaway climate change: On the timescale of centuries to millennia, the magnitude of global warming will be determined primarily by anthropogenic CO<sub>2</sub> emissions. This is due to carbon dioxide's very long lifetime in the atmosphere.
- Abrupt climate change: Climate change could result in global, large-scale changes in natural and social systems. Examples include ocean acidification caused by increased atmospheric concentrations of carbon dioxide, and the long-term melting of ice sheets, which contributes to sea level rise. Some large-scale changes could occur abruptly, i.e., over a short time period, and might also be irreversible. Examples of abrupt climate change are the rapid release of methane and carbon dioxide from permafrost, which would lead to amplified global warming.

### **Mitigation**

Mitigation of climate change refers to actions taken to reduce greenhouse gas emissions, or enhance the capacity of carbon sinks to absorb greenhouse gases from the atmosphere. There is a large potential for future reductions in emissions by a combination of activities, including energy conservation and increased energy efficiency; the use of low-carbon energy technologies, such as renewable energy, nuclear energy, and carbon capture and storage. Near- and long-term trends in the global energy system are inconsistent with limiting global warming at below 1.5 or 2 °C, relative to pre-industrial levels.

In limiting warming at below 2 °C, more stringent emission reductions in the near-term would allow for less rapid reductions after 2030. Many integrated models are unable to meet the 2 °C target if pessimistic assumptions are made about the availability of mitigation technologies.

### **Adaptation**

Climate change adaptation is another policy response. The adaptation may be planned, either in reaction to or anticipation of global warming, or spontaneous,

i.e., without government intervention. Planned adaptation is already occurring on a limited basis. The barriers, limits, and costs of future adaptation are not fully understood. Environmental organizations and public figures have emphasized changes in the climate and the risks they entail, while promoting adaptation to changes in infrastructural needs and emissions reductions.

Adaptation is especially important in developing countries since those countries are predicted to bear the brunt of the effects of global warming. That is, the capacity and potential for humans to adapt (called adaptive capacity) is unevenly distributed across different regions and populations, and developing countries generally have less capacity to adapt.

### **Glossary of related technical terms**

**(Source: IPCC)**

**Climate:** Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. WGIII

**Climate variability:** Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

**Climate change:** Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the

global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. WGIII.

**Abrupt climate change:** The nonlinearity of the climate system may lead to abrupt climate change, sometimes called rapid climate change, abrupt events, or even surprises. The term abrupt often refers to time scales faster than the typical time scale of the responsible forcing.

**Climate extreme (extreme weather or climate event):** The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes.'

**Radiative forcing:** Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in  $\text{W m}^{-2}$ ) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.

**Impacts:** Effects on natural and human systems. In this report, the term 'impacts' is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.

**Mean sea level:** Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean sea level is normally defined as the average relative sea level over a period, such as a month or a year, long enough to average out transients such as waves and tides.

**Sea level change:** Changes in sea level, globally or locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass and distribution of water and land ice, (iii) changes in water density, and (iv) changes in ocean circulation.

**Sea surface temperature (SST):** The sea surface temperature is the temperature of the subsurface bulk temperature in the top few meters of the ocean, measured by ships, buoys, and drifters.

**Vulnerability:** The propensity or predisposition to be adversely affected.

**Disaster:** Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

**Disaster management:** Social processes for designing, implementing, and evaluating strategies, policies, and measures that promote and improve disaster preparedness, response, and recovery practices at different organizational and societal levels.

**Mitigation** (of climate change): A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

**Adaptation:** In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.

**Adaptive capacity:** The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities.

**Coping:** The use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions, with the aim of achieving basic functioning in the short to medium term.

**Resilience:** The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.

**Scenario:** A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline.

**Climate scenario:** A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that

has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate.

**Climate projection:** A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative-forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

**Climate model:** A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved.

**Downscaling:** Downscaling is a method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.

**Emissions scenario:** A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as technological change, demographic and socioeconomic development) and their key relationships. Concentration scenarios, derived from emissions scenarios, are used as input to a climate model to compute climate projections.

**Greenhouse Gas:** Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, which absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes



the greenhouse effect. Water vapor (H<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>), and ozone (O<sub>3</sub>) are the primary greenhouse gases in the Earth's atmosphere.

**Greenhouse Effect:** Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. This is called the greenhouse effect. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.

*(Source: NASA, Wikipedia)*

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**Introduction**

Biodiversity is defined by the Convention on Biological Diversity (CBD) as the variability among living organisms from all sources including, among others, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 2016). Biological diversity includes species diversity, genetic diversity and ecosystem diversity. Species diversity is the diversity of all the species on earth from single celled bacteria and protists to all the species of the multicellular kingdom. Diversity in species shows the variation of species due to evolutionary and ecological adaptations of the species to the entire geographical range. Genetic diversity is the variation within species due to geographical separation and intraspecific variation within the population. As defined an ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interrelating as a functional unit. Ecosystem diversity is the variation of different biological communities and their interaction with the biotic and abiotic environment. Biological components are crucial in proper ecosystem functioning which provides essential ecosystem services to human beings.

**Climate change and Ecosystem services**

Marine and coastal ecosystems are the most vulnerable to the impacts of climate change which is occurring at a faster rate than ever in the human history. There are lots of pieces of evidences from the nature that climate change drastically affecting biodiversity. Especially the changes in the species distribution pattern, increased extinction rates of species, changes in the reproductive timings, development of new phenological traits and rate of the growing season in

plants. Among these, the increased rate of species extinction due to the human activities resulted in biodiversity loss and ultimately affected the supply of the ecosystem services to human well-beings. Many species showed changes in their distribution pattern in space and time. They have either expanded their distribution pattern towards poleward in latitude and upward in elevation. The restricted distribution pattern changed the population structure of species which already showing signs of decline due to the other non-climatic factors. Several fish species showed changes in the phenology such as breeding, spawning and migration due to climate change.

To address the biodiversity related issues, *i.e.* climate change, the over exploitation of living resources, damage due to dredging, reclamation wetlands, pollution, sea erosion, siltation, anthropogenic destruction of ecosystem, loss of biodiversity a thorough knowledge about the goods and services from the different marine ecosystems is a prerequisite. It is well established that there is no readymade solution to the serious biodiversity issues mentioned here. But, some of the International Agreements and treaties are good examples of the contemporary approaches to discover the answers to the fundamental issues through an exhaustive research and development of biodiversity. There is no single solution to the very complex issues mentioned above. But some of the approaches like, Convention on Biological Diversity (CBD), Ecosystem-Based Management (EBM), Millennium Ecosystem Assessment (MA), The Economics of Ecosystems and Biodiversity (TEEB), Intergovernmental Panel on Climate Change (IPCC) and Global Biodiversity Indicators (GBI) were discussed in the context of the issues and solutions to biodiversity crisis. For a better understanding of the impact of climate change on species and ecosystem, a thorough knowledge of four ecosystem services such as provisioning services, regulating services, supporting services and cultural and aesthetic services is a must. That knowledge will improve the existing climate resilient models and helps in reducing the uncertainties of prediction.

### **I. Ecosystem services from Marine and Coastal Ecosystems**

Marine ecosystems provide a wide variety of services to nature, which is essential for the well-being of the human population. The ecosystem services are classified into four *i.e.* provisioning services, regulating services, supporting services and cultural and aesthetic services. Provisioning services include the products gained from the environment in the form of food, natural crops, firewood, medicines, genes and ornamental resources, energy capitals, and product from bio prospecting. Regulating services comprise the coastline

equilibrium, flood prevention, storm shelter, climate regulation, hydrological services, nutrient regulation, carbon sequestration, deposition of contaminated waters and waste disposal. Supporting services are mainly the habitat provision, nutrient cycling, migration, seed dispersion, primary productivity and soil formation. Cultural and aesthetic services include the culture, tourism and recreation (Joshi and Vinodh, 2015).

### **1. Provisioning services**

Food provisioning in the form of fish landings and aquaculture products is one of the most important services obtained from the marine and coastal ecosystems. Mangroves are essential in supporting to fisheries owing to their function as fish nurseries and refuges. Mangroves help to increase fish production in the inshore waters near to it. Coral reefs also provide services like protection of breeders and larvae for the better survival and recruitment success of the resources (Joshi and Vinod, 2015). They form an important source of fisheries products for coastal populations and export markets. The coral reefs of the Gulf of Mannar, Andaman & Nicobar Islands, Lakshadweep Islands and Gulf of Kutch contribute substantially to the total marine finfish production of India. Other ecosystems like rocky intertidal, near shore mudflats, seagrass beds, mud bank areas, seamounts, brackish water, lagoons, estuaries, marshy areas and beaches also helps in the production of fish as food in one way or another.

The total marine fish landings from India were estimated at 3.95 million tonnes during 2017. Fisheries sector plays an important role in the Indian Economy, contributing about 1% to the national GDP. The sector provides livelihood to about 4 million fisher folk population along the coastal line of 8129 Km. The value of total marine fish landings at retail level was estimated at Rs. 78,408 crores during 2017. Since 1950 the marine fish production in India has gradually increased from mere 5.8 lakh tonnes (1950) to 3.59 million tonnes (2014) showing six-fold increase. Several of the marine and coastal ecosystems offer coastal populations with construction materials and building materials from the mining of marine ecosystems. Mangroves provide coastal and Island community with construction materials for boat building. Of the 33,059 total fish species from the world, India contributes of about 2492 marine fishes owing to 7.4% of the total marine fish resources. Of the total fish diversity known from India, the marine fishes constitute 76 percent, comprising of 2492 species belonging to 941 orders 240 families. Among the fish diversity-rich areas in the marine waters of India, the Andaman and Nicobar archipelago shows the highest number of species, 1431, followed by the east coast of India with 1121 species and the west

coast with 1071. As many as 91 species of endemic marine fishes are known to occur in the coastal waters of India (Joshi et al, 2017).

Among the products exported, shrimp product formed the major share about 3.0 lakh tonnes which form about 64% of the total value realized. Increased export demand often leads to expansion of mariculture practices. Coastal areas provide the foundation for the marketers which produce fisheries products from prawn, crab and fish. The factors affecting the marine fish production are the overexploitation, species extinctions and use of destructive methods of the fishing. The magnitude of marine fish stocks that are over exploited and declining are increasing over the last 30 years. It is reported that 133 extinctions of regional and global marine species occurred over the last 30 years. The major cause of the extinction was overexploitation (55%) and rest of habitat loss and other reasons (IUCN, 2018). Out of the 28 groups of finfishes studied by CMFRI, 20 were found to be under the abundant category, five under less abundant group and one each under declining, depleted and collapsed category. Elasmobranchs, threadfins, ribbonfishes, mullets and flatfishes are the five resource groups falling under less abundant category. Big-jawed jumper falls under declining category, flying fishes under depleted category and unicorn cod is the one that falls under collapsed category (Sathianandan *et al.*, 2011). Bio prospecting is the valuation of biodiversity for novel biological assets of social and economic value. It yielded several products from species in marine and coastal ecosystems. Coral reefs are important reservoirs of natural bioactive products many of which exhibit structural features not found in the terrestrial natural products. The pharmaceutical industry has discovered several potentially useful substances among sponges, jellyfish and Mollusca. CMFRI has developed nutraceuticals like Green Mussel Extract (GMe), Green Algal Extract (GAe) and Cadalmin Ade (Cadalmin extract) from marine mussel and seaweed.

**Marine ecosystems:** The topographical structures environment of the continental shelf and a dispersal array of fish and shellfish diversity in the coastal region as well as in the Exclusive Economic Zone (EEZ) differ from area to area along the Indian coast. Previous studies on the physical, chemical and biological oceanography of the seas around India have revealed that coastal waters (0-50 m) are fairly more productive (Devaraj *et al.*, 1998). Diversity in the species composite, typical of tropical seawaters and co-existence of dissimilar fish and shellfish species in the similar ground are significant features of Indian Marine Biodiversity. Historical readings on the biology and fishery features of the vital groups revealed that, most of the species supporting the fishery are short

lived with a normal life span up to 3-5 years, but the fishery being mostly supported by below a year olds and one-year-old. They are greatly prolific and spawn over lengthier periods typically with fractional spawning and display varied annual difference in recruitment. Several matters in the captive fisheries segment harmfully affect the marine biodiversity of the country, specifically in the fish as ecosystem good for human survivals. The difficulties like limitations of growth and production in the inshore trawling grounds, less cost-effectiveness and financial returns due to lesser cost of fishing operations, management difficulties in the framework of common property multi-user, multiple-choice nature of fisheries (Devaraj, 1996).

The above concerns brought about by the uncontrolled fishing effort put into the fishery without any respect to the stock-production-recruitment relationship. In addition, these the ecological problems mounded by cumulative pollution of coastal waters by release of crude sewages and pollutants by agro manufacturing centers working in the coastal zone. It has been witnessed that the sediment in certain waters comprises unusual levels of Copper, Zinc and Lead. The mercury content in some of the marine animals in certain places has been found to be higher than the normal, which may modify the genetic makeup of a species. The fly ash deposits from thermal plants in certain places are on the increase and it changes the bottom topography of the affected area and probabilities of species reduction and replacement.

The Bay of Bengal is much deeper than the Arabian Sea and more numbers of cyclonic storm's progress over the Bay of Bengal than the Arabian Sea. Periodic mean surface temperature over the Arabian Sea is highly variable from one season to another season, as compared to the Bay of Bengal. The lowest sea surface temperature in the Bay of Bengal was about 25 to 28°C throughout the winter period, but in other spells, it remains at 28.5 to 29°C. The Bay of Bengal is the one of the world's largest submarine fans which included large volumes of sediments discharged by the Ganges and Brahma Putra Rivers. The Bengal basin can be divided into Mahanadi – Godavari and Cauvery off shore basins and areas such as Vishakhapatnam – Chilka lake shelf and Madras-Pondicherry shelf. Central Bengal Bay has got an average depth of about 3400 m and numerous turbidity channels are present with a width of 5 to 27 km. South Bay of Bengal is characterized by the presence of a large number of sea mounts and coral Islands. They not only deliver food

and protection, but also for the breeding grounds for a large number of organisms. The Bay of Bengal shows moderate primary production in all the seasons as compared to the Arabian Sea (Devaraj, 1996).

**Mangrove ecosystems:** A large number of Islands along the Indian coastline in the Gulf of Mannar, Gulf of Kutch, Lakshadweep and Andaman group and the massive mangrove networks along the coast of Goa, Karnataka, Kerala, Tamilnadu, Andhra Pradesh and West Bengal constitute rich marine biodiversity supporting a diversity of species of corals, sponges, ornamental fishes, crustaceans, mollusks and plants. Indiscriminate fishing, mining, dredging, deforestation, industrialization, and other anthropogenic activities are the main pressures instigating significant damage to these environments and consequently to the associated flora.

**Coastal Ecosystems:** Distinguishing features of the Indian Ocean are the upwelling, southwest monsoon, northeast monsoon, mud-bank along the southwest coast and high coastal production. Upwelling happens in the area between Kanyakumari and Karwar during the beginning of southwest monsoon. It starts in the southern area first and then spreads northwards with the development of southwest monsoon. Southwest monsoon season is the period when mud-banks have formed in some places along the southwest coast of India particularly the Kerala coast. Mud banks of the Alleppey – region is formed by the subterranean mud and the Vembanad lake system provides the mud for this. The mud-banks between Parapanangadi and Tanur are the aggregation of coastal mud. The mud-banks at Chellanam, Narakkal, Valappad, Elathur, Quilandy, Muzhuppilangadi, Kottikulam, Adakathubali, Kumbala, Uppsala and Ullal are formed by the sediments and organic debris discharged from river and estuaries. Mud-banks at Vypeen are formed from dredging operation (Rao *et al.*, 1992). The optimum hydrographic condition in the southwest monsoon mouths, the salinity of water falls from 35‰ to 30-31‰ the temperature decreases from 31-32°C to 23-25°C and abundance of nutrients like phosphate, nitrate and silicate become abundant due to pulling and river discharges makes maximum phytoplankton production which is higher than some of the fertile seas of the world.

**Coral reef Ecosystems:** India is blessed with vast sections of coral reefs in the Gulf of Mannar and Palk Bay, Gulf of Kutch, South-west coast and along the Andaman & Nicobar and Lakshadweep islands. Coral reefs are the most biologically productive and diverse of all other natural ecosystems. Reefs are

equal to tropical rain forest for their rich biological diversity. Coral reefs have enormous amounts of calcium carbonate which forms the raw material for numerous lime waste, cement and calcium carbide industries. They are also used as building blocks in many parts of India. The finfish fauna of coral reefs is very rich and diverse. Moreover, they are raw materials for industries such as cement, lime and calcium carbide. A total of 225 species of corals is known from the Indian seas (Pillai, 1996). The coral reefs of India face numerous pressures from both natural and anthropogenic origin. Indiscriminate use of corals for many purposes, over exploitation of reefs associated fauna, dredging, reclamation, are important anthropogenic factors for the damage of corals in India. Pollution, sea erosion, siltation, constructive activities in brackish water lagoons also added to this man made cause of destruction of reefs. Global warming, coral bleaching, cyclones, white band diseases, pest attacks by *Acanthaster planci* are some of the natural cause affect mortality of corals.

**Estuarine ecosystems:** The total brackish water assets of India as projected by the Government of India were 1.44 million ha. Orissa, Gujarat, Kerala and West Bengal have vast brackish water assets. West Bengal is gifted with the rich brackish water zone, estimated to be 405,000 ha with Hooghly-Matlah estuary accounting for the 8,029 km<sup>2</sup> and part of Sunderbans to be 2,340 km<sup>2</sup>. Orissa has an over-all brackish water resources of 417,537 ha. Estuaries, lakes and backwater account for 247,850 ha, 79,000 ha and 8,100 ha correspondingly. The Mahanadi estuary lies in the Cuttack and Puri districts of Orissa and drains into the Bay of Bengal. The major fauna includes *Tenualosa ilisha*, *Nematalosa nasus*, *Sardinella* sp., *Ilisha* sp., *Mugil cephalus*, *Planiliza parsia* and other perches. Estuaries face difficulties of absence of realistic planning and coordinated among the diverse stakeholders in the implementation of management option, lack of critical knowledge on the environmental principles as well as sustainable management of assets, and low level of knowledge in the biodiversity worth of goods and services providing by estuary.

**Lagoon Ecosystem:** A lagoon is a low water body along the low lying coast, parted from the ocean by a barrier and also linked to the sea by creeks or estuary at one or two places. Of the total of 17 major lagoons occur along the coast of India the main lagoons are Chilka Lake, Gulf of Mannar, Muthupet, Muthukkadu, Nizampatanam, Pennar, Pulikat Lake, Vembanad Lake, Ashtamudi Lake, Ettikulum, Paravur Lake, Murukkanpuzha, Talapdy, Veli Lake, Lagoons of Bombay, and Lakshadweep atolls (Alok Saxena, 2012). The lagoon ecosystems are the most susceptible ecosystems due to numerous anthropogenic actions



which threaten flora and fauna of the system. Pressures consist of pollution from industries, discarding of urban sewage, recreational boating, navigation, the growth of urban and rural settlements, reclamation, over exploitation of fish stocks, intensive aquaculture practices and effluents from different sources.

The Chilka lagoon is the principal brackish water lagoon on the east coast of India and is chosen as a Ramsar site since 1981. The area during the summer and rainy season has been estimated to be 906 and 1,105 km<sup>2</sup> respectively. The brackish water of Andhra Pradesh is about 2.0 lakh ha and mangrove swamp of 27,500 ha which supports about 268 species of fishes which includes *Nematalosa nasus*, *Mystus gulio*, *Planiliza macrolepis*, *Tenualosa ilisha* and *Gerres setifer*. Pulicat Lake is a very important brackish water lake of Nellore district of Andhra Pradesh and the rest of Tamil Nadu region with an overall area 77,000 ha. The fishery comprises of *Nematalosa nasus*, *Planiliza macrolepis*, *Sillago sihama*, *Chanos* etc. The Godavari estuarine system has an area of 330 km<sup>2</sup> drains to Bay of Bengal on the east coast in the state of Andhra Pradesh. The major fisheries are formed by *Gerres filamentosus*, *Caranx* sp., *Sillago sihama*, *Platycephalus* sp., *Lates calcarifer* and *Mugil cephalus* (Joshi *et al*, 2017).

## 2. Regulating services

Regulating services are the benefits people obtained from the regulation of ecosystem processes, including air quality maintenance, erosion control, regulation of human diseases and water purification. The mangroves, sea grass, coral reefs, rocky intertidal, mudflats, and deltas play key role in shoreline stabilization, protection from storms, tidal waves and soil loss, dispensation of pollutants and stabilizing land in the event sea level surge. Estuaries are main buffer regions as it is a conversion zone between freshwater environments and are subject to marine effects such as tides, waves and incursion of saline water, fresh water and sediment. This influx of both marine and fresh water carries lots of nutrients in both water and sediment makes them most productive habitats in the world. India has rich estuarine and other brackish water assets along the east and west coasts formed by the rivers. Mangroves give fortification to the coastline from natural calamities like Hurricane, flood and Tsunami. Mangroves have great ability to absorb heavy metals and other toxic substances, coral reefs buffer land from storms and prevent beach loss. Estuaries, lagoons, marshes, brackish water areas play a crucial role in preserving the hydrological balance and cleaning water of pollutants. Marine ecosystems play important roles in climate regulation. CO<sub>2</sub> is constantly exchanged between the atmosphere and

ocean; it dissolves in surface waters and is then transported to the deep ocean. Marine plants fix CO<sub>2</sub> during photosynthesis in the ocean and return it via respiration.

### **3. Supporting Services**

Many species use coastal areas like estuaries, mangroves, sea grass beds as nurseries. Estuaries are used as the major as nursery areas for finfishes and other species and they form one of the strongest linkages between coastal, marine and freshwater ecosystems and the ecosystem services they provide. The success of the prawn fishery mainly depends on the migration of prawns through the estuary. Mangroves provide nursery for many species as well as give links to sea grass beds with associated coral reefs. Mangroves are good breeding and nursery grounds for a variety of prawns and fishes. It offers nutrition for many organisms through recycling of plant and animal remnants. Decline in the area of mangroves can interrupt these linkages and cause biodiversity loss which results in lower productivity from the reef and sea grass beds.

### **4. Cultural and Aesthetic Services**

Cultural services comprise of tourism and recreation, visual and spiritual services, traditional knowledge and education and research amenities. Mangrove ecosystem delivers services like, opportunities for boating, hunting, bird watching, wildlife observation, education excursions for specimen gathering and photography. Apart from these activities, in many species are dependent on mangroves and estuaries for their survival.

## **II. Approaches to Link Climate change and biodiversity**

The mainstream theories have set new avenues for the research and progress in the Life sciences. Biodiversity researchers per say adapted several new approaches during the recent years to find solutions to biodiversity loss and conservation. The simple tool for the sustainable growth has an inclination to oversee the scientific uncertainties in an unrealistic routine. The recent tactics and instruments like the Convention on Biological Diversity (CBD), Ecosystem-based management, Millennium Ecosystem Assessment, The Economics of Ecosystems and Biodiversity (TEEB), Intergovernmental Panel on Climate Change (IPCC) developed for the sustainable development and conservation of biodiversity can be considered as a neorealistic approach.

### **1. Convention on Biological Diversity (CBD)**

The Convention on Biological Diversity (CBD) come into power on 29<sup>th</sup> December 1993 has 3 main goals: The conservation of biological diversity; the

sustainable use of the components of biological diversity; the rational and equitable distribution of the benefits arising out of the exploitation of genetic resources. The Convention on Biological Diversity was stimulated by the world community's mounting obligation to sustainable growth. It characterizes a dramatic step onward in the conservation of biological diversity, the sustainable use of its constituents, and the reasonable and rightful allotment of benefits arising from the practice of genetic assets.

## **2. Ecosystem Based Management (EBM)**

Ecosystem-based management is an agenda for evolving effective management plans created with an accepted set of guiding principles. An ecosystem-based management plan should: highlight the health of the whole ecosystem ahead of the alarms of special benefits; be focused on a specific place, with frontiers that are logically defined; an account of the customs in which things or activities in that place affect each other; consider the way the things or actions in this place can impact or be influenced by things or activities on land, in the air, or in diverse portions of the ocean; and assimilate the concerns of the environment, humanity, the economy and our organizations (UNEP, 2018).

## **3. Millennium Ecosystem Assessment (MA)**

The Millennium Ecosystem Assessment assessed the apprehensions of ecosystem alteration in social well-being from 2001 to 2005 and it involved the effort of more than 1360 specialists worldwide. The previous 50 years, humans have altered ecosystems more quickly and widely than in any similar period of time in human history, mainly to meet fast growing demands for essential items like food, fresh water, timber, fiber and fuel. This has caused in a considerable and chiefly irreparable damage in the diversity of life on Earth. Millennium Ecosystem Assessment provided a valued logical evaluation of the condition and trends in the world's environment and the services they provide, as well as the logical basis for action to protect and use them sustainably. The task of backing the degradation of ecosystem while gathering increasing hassles for amenities can be moderately met in some situations measured by the MA, but will include important variations in strategies, organizations and performs that remain not presently below mode. Numerous choices occur to preserve or improve precise ecosystem services in means that lessen undesirable trade-offs or that deliver helpful collaborations with other ecosystem services (MA, 2018).

## **4. The Economics of Ecosystems and Biodiversity (TEEB)**

The Economics of Ecosystems and Biodiversity (TEEB) is an international initiative concentrated on "making nature's values visible". Its major objective is

towards mainstream the values of biodiversity and ecosystem services into policy making at all levels (TEEB, 2018). To attain this objective by succeeding an organized method of valuation that helps policy makers to distinguish the wide array of paybacks provided by ecosystems and biodiversity, establish their value in economic terms and, wherever suitable, capture those values in policy making. In March 2007, environment ministers from the G8+5 countries meeting in Germany planned to initiate the procedure of evaluating the global economic value of biological diversity, the overheads of the loss of biodiversity and the catastrophe to take protective measures against the prices of effective conservation (TEEB, 2018).

### **5. Intergovernmental Panel on Climate Change (IPCC)**

The Intergovernmental Panel on Climate Change (IPCC) is the foremost global body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to deliver the world with a vibrant technical view on the present state of knowledge on climate change and its possible ecological and socioeconomic bearings (IPCC, 2018). It analyses and evaluates the most recent scientific, technical and socioeconomic information produced globally pertinent to the understanding of climate change. Thousands of scientists from all over the world contribute to the effort of the IPCC on a voluntary basis. Appraisal is a vital part of the IPCC procedure, to safeguard an objective and whole assessment of presenting data. IPCC targets to replicate a variety of opinions and knowledge. The Secretariat organizes all the IPCC work and communicates with Governments (IPCC, 2018).

### **III. Global Biodiversity Indices (GBI)**

Global Biodiversity Indicators are statistical measures of biodiversity which benefit experts, managers and legislators realize the condition of biodiversity and the factors that disturb it. These indicators allow managers and legislators to see if their resolutions are protecting biodiversity or leading to its degradation and loss. Without this information it is not imaginable to distinguish if the activities being taken are working and should continue or if different methods need to be tried. Some of the important GBIs currently in use include; Living planet Index (LPI), Wild Bird Index (WBI), Red List Index (RLI), Marine Trophic Index (MTI), Forest extent, Ecological Footprint, Number and distribution of Invasive Alien Species (IAS), Proportion of fish stocks that are fully exploited, over-exploited or depleted, Extent of Protected Areas (PAs) (CBD, 2016).

### **Climate change and Sustainable utilization of Marine Resources**

The various approaches mentioned above are recent origin and needs to be tested for the effectiveness for an array of different species regimes occupies in a wide range of habitats of concerned ecosystems. The fact that the rate of degradation of ecosystem and the rate of extinction of species during the past decade from the biosphere is faster than it occurs during the period of nineteen centuries. Hence, immediate steps needed to be taken to reduce or to sustain a balance between the extinction rates of species from the biosphere. But at the human population shows unprecedented growth over the years which necessitates the use of more and more natural resources. In order to meet the growing needs increasing and sustainable use of resources, equitable distribution of benefits arising from the ecosystem and to preserve it for the future generation is to use it. The ecosystem goods and services provided by the fauna and flora and the interrelationship between the biodiversity and ecological processes are the fundamental issues in the sustainability and the equilibrium of the ecosystem. Several of the marine resources like seaweeds, sponges, gorgonids, corals, sea horses and others are being exploited for the extraction of pharmaceuticals, active substances which are recognized to cure numerous diseases. While there are reports of over utilization of certain of these assets, there are also reports of ecological degradation due to anthropogenic influences. Certain delicate and sensitive marine ecosystems will not exist in the future, if suitable care is not taken to protect the system. In order to attain better returns while protecting the environment, an appropriate policy needs to be framed to exploit the assets on sustainable levels, to extract the drugs indigenously, mostly for domestic use and for limited export. It is realized that there is an inclination for severe exploitation of exportable commodities, but the country cannot lose sight of the need to protect biodiversity and meet national requirements in its offer to increase foreign exchange earnings.

It is well known that the resilience of ecosystems can be improved and the jeopardy of damage to human and natural biotas reduced through the implementation of biodiversity-based adaptive and mitigating strategies. Mitigation is designated as a human involvement to reduce greenhouse gas sources or augment carbon sequestration, while adapting to climate change denotes to modifications in natural or human systems in response to climatic change, which controls damage or exploits beneficial opportunities. Some of the examples of actions that encourage mitigation or adaptation to climate change are preserving and, restoring natural ecosystems, protecting and enhancing ecosystem services, managing habitats for endangered species, creating national

parks, refuges, protected areas, and buffer zones, establishing networks of marine protected areas in order to account probable fluctuations in climate.

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### Introduction

Multivariate Analysis is concerned with statistical methods designed to elicit information from data sets which include measurements on many variables. These techniques have emerged as a powerful tool to analyse data represented in terms of many variables. The main reason being that a series of univariate analysis carried out separately for each variable may lead to incorrect interpretation of the result and the inferences drawn may be misleading. This is so because univariate analysis does not consider the inter-dependence among the variables. These techniques are used in analyzing social, psychological, medical and economic data, especially when the variables concerning research studies of these fields are supposed to be correlated with each other and when rigorous probabilistic models cannot be appropriately used. Applications of multivariate techniques in practice have been accelerated in modern times because of the advent of high speed electronic computers.

The objectives of scientific investigations for which multivariate methods are commonly used are

- *Data reduction or structural simplification.* The phenomenon being studied is represented as simply as possible without sacrificing valuable information.
- *Sorting and Grouping.* Groups of similar objects or variables are created based upon measured characteristics.
- *Investigation of the dependence among variables.* The nature of the relationships among variables is of interest. Are all variables mutually independent or are one or more variables dependent on others? If so, how?
- *Prediction.* Relationships between variables must be determined for the purpose of predicting the values on the basis of observation on the other variables.



- *Hypothesis testing.* Specific statistical hypotheses, formulated in terms of the parameters of multivariate populations are tested.

### Multiple Linear Regression

Multiple regression is the most commonly utilized multivariate technique. It is a statistical technique that simultaneously develops a mathematical relationship between two or more independent variables and an interval scaled dependent variable. It examines the relationship between a single dependent variable and two or more independent variables. The technique relies upon determining the linear relationship with the lowest sum of squared variances.

Let  $x_1, x_2, \dots, x_k$  be  $k$  independent variables assumed to be related to a response variable  $y$ . The classical linear regression model states that  $Y$  is composed of a mean, which depends in a continuous manner on  $x_i$ 's and random error  $\varepsilon$ .

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + \varepsilon.$$

The beta coefficients (weights) are the marginal impacts of each variable, and the size of the weight can be interpreted directly.  $\beta_0$  is the  $y$ -intercept or constant,  $\beta_1$  is the coefficient on the first predictor variable,  $\beta_2$  is the coefficient on the second predictor variable, and so on.  $\varepsilon$  is the error term or the residual that can't be explained by the model. The estimates of  $\beta$ 's represented by  $b_0, b_1, b_2, \dots, b_k$  that minimize the squared deviations between the expected and observed values of  $Y$  are obtained by least square approach. This gives us a regression equation used for prediction of

$$y = b_0 + b_1 x_1 + b_2 x_2 + \dots + b_k x_k$$

The multiple regression model is based on the following assumptions:

- There is a linear relationship between the dependent variables and the independent variables
- The independent variables are not too highly correlated with each other
- $y_i$  observations are selected independently and randomly from the population
- Residuals should be normally distributed with a mean of 0 and variance  $\sigma^2$

Multiple regression is often used as a forecasting tool. The multiple regression model allows an analyst to predict an outcome based on information provided on multiple explanatory variables. Still, the model is not always perfectly accurate

as each data point can differ slightly from the outcome predicted by the model. The residual value,  $e$ , which is the difference between the actual outcome and the predicted outcome, is included in the model to account for such slight variations. How well the equation fits the data is expressed by  $R^2$  the "coefficient of determination."  $R^2$  is a statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable. It is indicative of the level of explained variability in the data set and is used as a guideline to measure the accuracy of the model.  $R^2$  can only be between 0 and 1, where 0 indicates that the outcome cannot be predicted by any of the independent variables and 1 indicates that the outcome can be predicted without error from the independent variables. One way of interpreting this figure is to say that the variables included in a given model explain approximately x% of the observed variation. So, if the  $R^2 = 0.50$ , then approximately half of the observed variation can be adequately explained by the model.

### **Cluster Analysis**

Cluster analysis is a multivariate method which aims to classify a sample of subjects (or objects) on the basis of a set of measured variables into a number of different groups such that similar subjects are placed in the same group. It is an exploratory data analysis tool which aims at sorting different objects into groups in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. Cluster analysis can be used to discover structures in data without explaining why they exist. In cluster analysis, there is no prior information about the group or cluster membership for any of the objects. Cluster analysis has no mechanism for differentiating between relevant and irrelevant variables. Therefore the choice of variables included in a cluster analysis must be underpinned by conceptual considerations. There are a number of different methods that can be used to carry out a cluster analysis which are classified as follows:

### **Hierarchical methods**

A hierarchical procedure in cluster analysis is characterized by the development of a tree like structure. A hierarchical procedure can be agglomerative or divisive.

**Agglomerative methods** in which subjects start in their own separate cluster. The two 'closest' (most similar) clusters are then combined and this is done repeatedly until all subjects are in one cluster. At the end, the optimum number of clusters is then chosen out of all cluster solutions. Agglomerative

methods in cluster analysis consist of linkage methods, variance methods, and centroid methods. Linkage methods in cluster analysis are comprised of single linkage, complete linkage, and average linkage.

**Divisive methods** in which all subjects start in the same cluster and the above strategy is applied in reverse until every subject is in a separate cluster.

### **Non-hierarchical methods (k-means clustering methods)**

It follows a simple procedure of classifying a given data set into a number of clusters, "k," which is fixed in advance. This method will categorize the items into k groups of similarity using the Euclidean distance as measurement. The clusters are then positioned as points and all observations or data points are associated with the nearest cluster, computed, adjusted and then the process starts over using the new adjustments until a desired result is reached.

The choice of clustering procedure and the choice of distance measure are interrelated. The relative sizes of clusters in cluster analysis should be meaningful. The clusters should be interpreted in terms of cluster centroids. The variables on which the cluster analysis is to be done should be selected by keeping past research in mind. It should also be selected by theory, the hypotheses being tested, and the judgment of the researcher.

### **Principal component analysis**

Principal component analysis (PCA) is a technique used to emphasize variation and bring out strong patterns in a dataset. Principal Component Analysis (PCA) is a dimension-reduction tool that can be used to reduce a large set of variables to a small set that still contains most of the information in the large set. One way of reducing the number of variables is to consider some of the linear combinations of these variables only. Principal component analysis (PCA) is a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. We can discard those linear combinations which have smaller variances and consider only those combinations which have high variances. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. Principal components are linear combinations of the statistical or random variable which have special properties in terms of the variances. For example, first PC is the normalized linear combination of the original variable with maximum variance. The second PC is the normalized linear combination,

which has the second maximum variance and uncorrelated with first PC .The total variance of the variables equals the total variance of the components.

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables.

Let  $X$  be the component vector with variance-covariance matrix  $\Sigma$  . Since we are interested in the variances and co-variances, we have suppose that  $E(X) = 0$ . Let  $\beta$  be the component vector such that  $\beta'\beta = 1$  and  $v(\beta) = \beta'\Sigma'\beta$  is maximum. The vector of principal component is the solution of  $(\Sigma - \lambda I) = 0$ . Then the first principal component is  $U_1 = \beta'X$  and the variance is the largest root of  $|\Sigma - \lambda I| = 0$  and  $v(\beta'X) = \lambda_1$ .

The Eigen vectors of a square matrix are the non-zero vectors that, after being multiplied by the matrix, remain parallel to the original vector. For each Eigen vector, the corresponding Eigen value is the factor by which the Eigen vector is scaled when multiplied by the matrix. The prefix Eigen is adopted from the German word "Eigen" for "self" in the sense of a characteristic description. The Eigen vectors are sometimes also called characteristic vectors. Similarly, the Eigen values are also known as characteristic values.

The mathematical expression of this idea is as follows; if a square matrix  $A$ , a non-zero vector  $v$  is an Eigen vector of  $A$  if there is scalar  $\lambda$  such that

$$Av = \lambda v$$

Then scalar  $\lambda$  is said to be the Eigen value of  $A$  corresponding to  $v$ . An Eigen space of  $A$  is the set of all Eigen vectors with the same Eigen value together with the zero vector. However, the zero vector is not an Eigen vector.

### Steps in PCA

- Standardize the data.
- Perform Singular Vector Decomposition to get the Eigenvectors and Eigenvalues.
- Sort eigenvalues in descending order and choose the  $k$ - eigenvectors
- Construct the projection matrix from the selected  $k$ - eigenvectors.
- Transform the original dataset via projection matrix to obtain a  $k$ -dimensional feature subspace.

It is mostly used as a tool in exploratory data analysis and for making predictive models. Often its operation can be thought of as revealing the internal structure of the data in a way that best explain the variance in the data. If a multivariate data set is visualized as asset of coordinates in a high dimensional data space, principal component analysis can supply the user with a low-dimensional structure, a shadow of this object when viewed from its most informative view. This can be done by using only the first few principal components so that dimensionality of the transformed data is reduced. The principal component analysis is concerned with explaining the variance covariance structure through a few linear combinations of the original variables. Its general objectives are data reduction and interpretation.

### **Canonical Correlation**

Canonical correlation analysis (CCA) is a way of measuring the linear relationship between two multidimensional variables. It is the multivariate extension of correlation analysis. It finds two bases, one for each variable, that are optimal with respect to correlations and, at the same time, it finds the corresponding correlations. The aim of canonical correlation analysis is to find the best linear combination between two multivariate datasets that maximizes the correlation coefficient between them. This is particularly useful to determine the relationship between criterion measures and the set of their explanatory factors. This technique involves, first, the reduction of the dimensions of the two multivariate datasets by projection, and second, the calculation of the relationship (measured by the correlation coefficient) between the two projections of the datasets.

It is the multivariate extension of correlation analysis. Ordinary correlation analysis is dependent on the coordinate system in which the variables are described. This means that even if there is a very strong linear relationship between two multidimensional signals, this relationship may not be visible in an ordinary correlation analysis if one coordinate system is used, while in another coordinate system this linear relationship would give a very high correlation. Canonical correlation analysis finds the coordinate system that is optimal for correlation analysis. CCA connects two sets of variables by finding linear combinations of variables that maximally correlate.

The major purposes of CCA are:

- Data reduction: explain covariation between two sets of variables using small number of linear combinations

- Data interpretation: find features (i.e., canonical variates) that are important for explaining covariation between sets of variables

The canonical correlation technique is to find several linear combinations of X variables and the same number of linear combination of Y variables in such as these linear combination best express the correlation between the two sets. These linear combinations are called the canonical variables. The correlation between the corresponding pairs of canonical variables is called canonical correlation.

Suppose we desire to examine the relationship between a set of variables  $x_1, x_2, \dots, x_p$  and another set  $y_1, y_2, \dots, y_q$ . And the sample means for all x and y variables are zero. The first step in canonical correlation is to form two linear combinations:

$$W_1 = a_{11}x_1 + a_{12}x_2 + \dots + a_{1p}x_p$$

$$V_1 = b_{11}y_1 + b_{12}y_2 + \dots + b_{1q}y_q$$

such that  $\text{corr}(W_1, V_1) = C_1$  is maximum.

Then the second step is to identify another set of canonical variables

$$W_2 = a_{21}x_1 + a_{22}x_2 + \dots + a_{2p}x_p$$

$$V_2 = b_{21}y_1 + b_{22}y_2 + \dots + b_{2q}y_q$$

such that  $\text{corr}(W_2, V_2) = C_2$  is maximum and  $\text{corr}(W_1, W_2) = 0, \text{corr}(V_1, V_2) = 0$ .

The process of extracting canonical variables can be repeated until the number of canonical variables equals the number of original variables or the number of classes minus one, whichever is smaller.

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**Introduction**

Molluscs are a fascinating and varied group of animals and although their outside features may vary greatly in form and colour, their internal structure are constant. The invertebrate phylum Mollusca with more than 80,000 species is second only to Arthropoda in number of species.

In India, the molluscs contribute to important fisheries, providing nutritious food, and are also foreign exchange earners to the country. The shell has many industrial uses and is the object in making eye-catching articles by deft craftsmen. Men, women and children participate in fishing molluscs, which provide employment and income in coastal rural areas.

**Magnitude of Molluscan Fisheries in India**

Cephalopods are by far the most important group with an average annual production of about 1,05,000 tonnes (see Fig.1). They are landed as by-catch and as a targeted fishery mostly in mechanized trawlers operating up to 200 m depth for subsoil shell deposits for industrial purposes is a major activity in the Ashtamudi and Pulicat Lakes. Kerala dominates bivalve production, which includes oysters, mussels and clams. However unlike cephalopod production estimate which is based on a scientifically valid methodology; the estimates for bivalve production is mostly region specific, and therefore, the error of the estimates are likely to be high.

TN and KL states contribute to almost all of the production. These estimates are likely to be gross underestimates due to low taxonomic resolution of the data set.

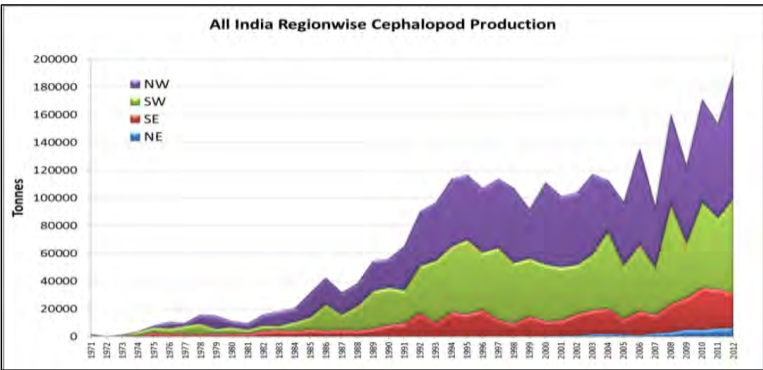


Figure 1: Region wise estimated cephalopod production from Indian seas during 1971-2012. Note the overall dominance of northwest and southwest coasts.

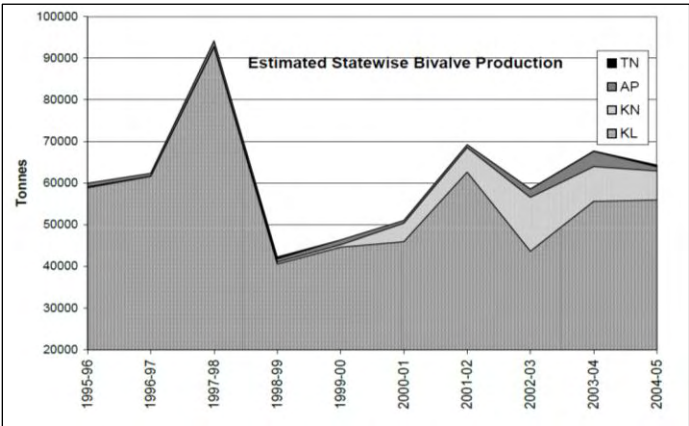


Figure 2: Estimated state wise bivalve production in India.

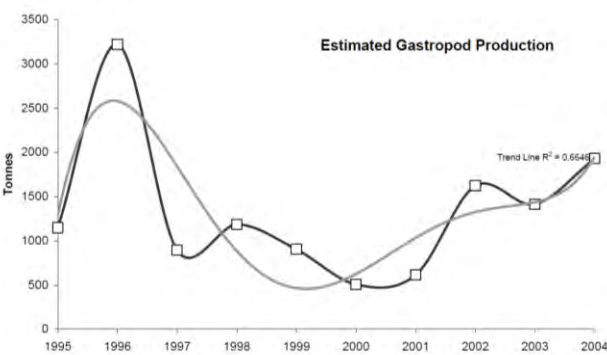


Figure 3: Estimated annual gastropod production in India along with trend line.



## Bivalve Fishery

A variety of clams, oysters, mussels and the windowpane oysters are distributed along the Indian coastline where they are fished by the local people. Clams and cockles form 73.8%, followed by oysters (12.5%), mussels (7.5%) and windowpane oysters (6.2%). The major bivalve resources and their total landing are given in Table.1 and Fig.2. The production levels in other states are meagre. Information on the bivalve production from the NE and NW states are scanty.

## Utilization

India has been exporting bivalves especially clam and mussel meat to other nations (Fig.4). The average foreign exchange earned by the nation during 1991-2003 through bivalve and gastropod exports is Rs.13 crores from the export of 1998 t of various products like frozen, smoked and dried meat and seashells. Bivalves fished along the West Coast are utilized for human consumption. Some bivalve products like smoked and canned oysters have good market in Indian metro cities. In Kerala and Andhra Pradesh part of the clam landings are used as a major ingredient of shrimp feed. The extensive shrimp farms also use dried and boiled clam meat as shrimp feed. Apart from these, the shells of bivalves are used in the manufacture of cement, calcium carbide, sand-lime bricks and lime. The lime shell is used as manure in coffee plantations, as mortar in building construction, in the treatment of effluents, as a pesticide by mixing with copper sulphate and in glass, rayon, polyfibre, paper and sugar industries. Bivalve shells with attractive sculpture are used by the ornamental shell craft industry. The shells of giant clams, winged oysters and black lip pearl oysters are used as curios in the Island territories.

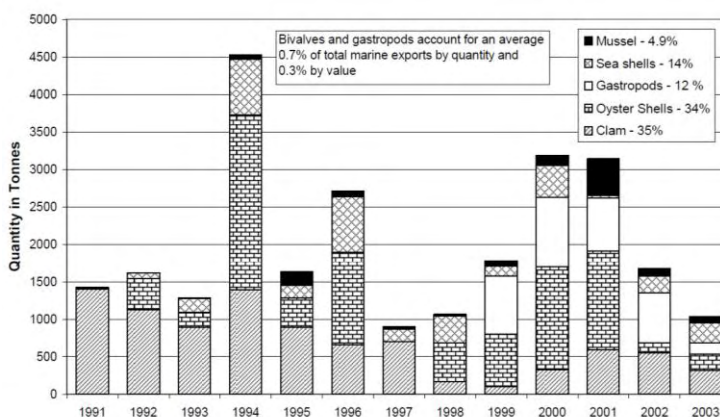


Figure 4: Export of bivalve and gastropod products from India.

Major contributors are clams and oyster shells. There is great scope for increasing the quantity and value through product diversification and addressing niche markets. (Data source: MPEDA, Cochin).

### Stock assessment

Only few studies have been made to assess the stock of bivalves. However, short term surveys have been conducted in the estuaries and coastal regions of maritime states to study the standing stock bivalve resource. Using the standing stock estimates by CMFRI the potential yield of bivalves has been estimated (Table.1). The present status shows that the clam and oyster resources are underutilized in Gujarat and Maharashtra and effort to utilize these resources should be enhanced. However bivalves have varied reproductive potential hence these resource estimates have to be revalidated frequently. In other states like Kerala and Karnataka the resources are utilized and in some regions they require conservation.

### Management Strategies

Bivalves offer one of the important examples of marine resource management along the Indian coast. However, apart from the restriction on the pearl oyster fishery by the Government of Tamil Nadu, and the management measures on the short-neck clam fishery of Ashtamudi Lake, Kerala, there are no regulations for effective utilization and conservation of these sedentary marine resources. One of the major bivalve resources, the short-neck clam (*P. malabarica*) is well protected by the following regulations formulated by the Government of Kerala based on recommendations made by CMFRI. a) Ban on fishing 28 Winter School on ICT-oriented Strategic Extension for Responsible Fisheries Management activity during breeding season (September to February), b) use of gears with 30 mm mesh size to avoid exploitation of smaller clam, c) Restrict the grade of export of frozen clams meat to 1400 nos/kg and above and d) Initiate semi-culture or relaying of small clams. One of the major drawbacks in bivalve fishery management is that there is no proper data collection system on the fishery landings. A proper database on the resource availability and their utilization pattern is essential.

Table 1. Standing stock and potential yield estimates of bivalves

| Resource/State           | Estimated Standing Stock | Potential Yield Estimate |
|--------------------------|--------------------------|--------------------------|
| <b>Clams and Cockles</b> |                          |                          |
| Maharashtra              | 4000                     | 5000                     |
| Goa                      | 1200                     | 2000                     |
| Karnataka                | 8027                     | 6823                     |
| Kerala                   | 65000                    | 55250                    |

|                           |               |               |
|---------------------------|---------------|---------------|
| Tamil Nadu & Pondicherry  | 5770          | 4905          |
| Andhra Pradesh            | 58000         | 49300         |
| <b>Total</b>              | <b>141997</b> | <b>123278</b> |
| <b>Oysters</b>            |               |               |
| Gujarat                   | 1500          | 1050          |
| Maharashtra               | 335           | 235           |
| Karnataka                 | 450           | 315           |
| Kerala                    | 4200          | 2940          |
| Tamil Nadu                | 19032         | 13322         |
| Andhra Pradesh            | 23000         | 16100         |
| <b>Total</b>              | <b>48517</b>  | <b>33962</b>  |
| <b>Mussel</b>             |               |               |
| Maharashtra               | 1800          | 1260          |
| Goa                       | 1120          | 784           |
| Karnataka                 | 9800          | 6860          |
| Kerala                    | 17473         | 12231         |
| Tamil Nadu                | 350           | 245           |
| Andhra Pradesh            | 1000          | 700           |
| <b>Total</b>              | <b>31543</b>  | <b>22080</b>  |
| <b>Windowpane Oysters</b> |               |               |
| Gujarat                   | 5000          | 3500          |
| Goa                       | 120           | 84            |
| Andhra Pradesh            | 12420         | 8694          |
| <b>Total</b>              | <b>17540</b>  | <b>12278</b>  |
| <b>Grand Total</b>        | <b>239597</b> | <b>191598</b> |

### Ashtamudi Lake Clam Fisheries Management Plan

Part of Zone I, under and west of the Neendakara Bridge should be declared as a no-take zone for clams all through the year. This will function as a protective zone where in regenerations of stocks will take place continuously and this will also help re-populate clams in other zones. This zone can function as a CLAM SANCTUARY. The provision of Declared Fisheries Zone (DFZ) of the Kerala Inland Fisheries Act may be invoked for this purpose by the State.

Seed clams can be transplanted and cultured in shallow areas having similar water and sediment conditions of the clam beds. The suitable areas for such transplant culture are indicated in the report of Suja (2012) and an example GIS map is shown below (Fig.9). The optimum stocking densities are also indicated in this report.

Seed clams below 20 mm APM should not be allowed to be harvested, and if harvested, they should be relayed. This size may be declared as the Minimum Legal Size (MLS) for harvest by the DOF.

As a long-term conservation measure, hatcheries have to be developed within the next 10 years for breeding the clams and spats can be relayed in suitable locations (indicated above) in Ashtamudi Lake.

Transplantation of clams from one estuary to another must not be permitted as the ecological effects cannot be easily judged beforehand.

No species introductions should be permitted in Ashtamudi Lake without a comprehensive study by a research institute and permission of the SFD.

### Ashtamudi Lake – A managed Clam Fishery

The short-neck clam fishers (numbering about 500 fulltime and part time fishers) of Ashtamudi Lake are perhaps one of the best examples of a well-managed local fishery benefiting the fishers and maintaining sustainable harvests. The management practices are implemented by the cooperative societies with the active scientific support of CMFRI.

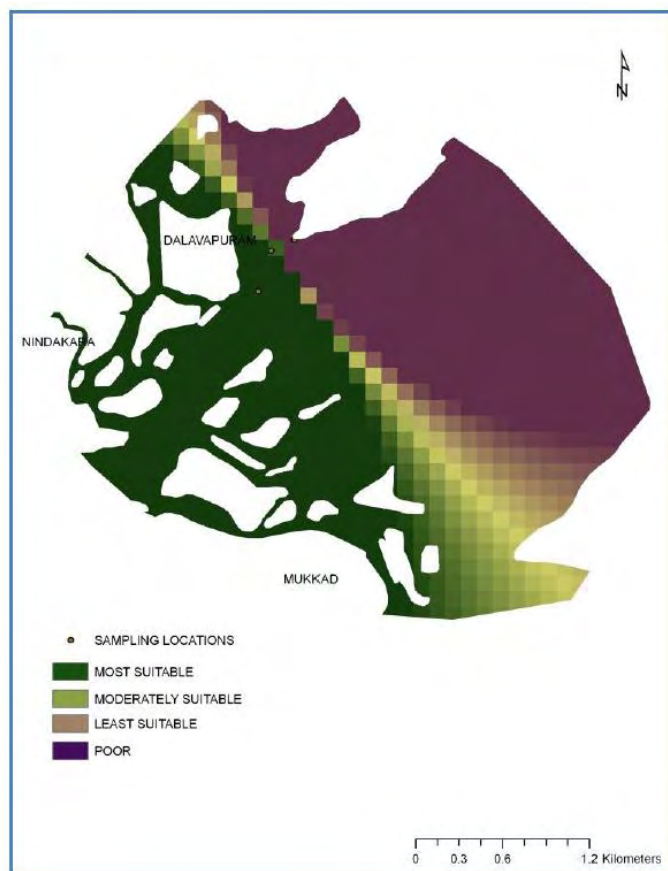
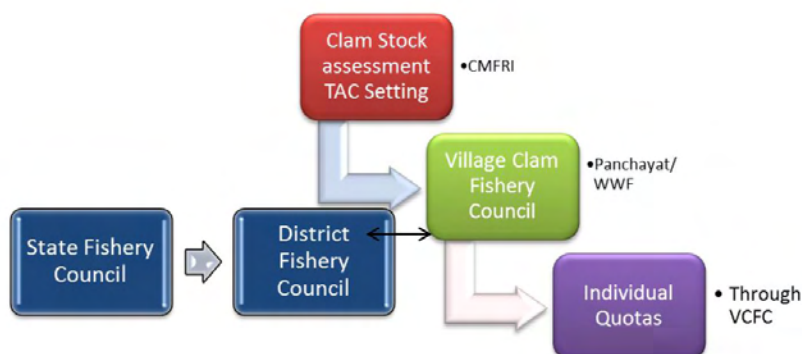


Figure 5: GIS map showing areas suitable for clam transplantation (farming) in Ashtamudi Lake. From Suja (2012)

A system of licensing of clam fishers in the Lake and registration of boats and gears used for clam fishing should be urgently carried out by the SFD.

No mechanical devices should be permitted for the harvest of clams in the Lake. The CMFRI should conduct clam biomass surveys in Jan-Feb every year, and come out with estimates of fishable stock in the ensuing season. The CMFRI should provide sufficient information to generate a Total Allowable Catch (TAC) which can be later converted to individual quotas for fishers on an annual basis. 30 Winter School on ICT-oriented Strategic Extension for Responsible Fisheries Management. For effective management of the clam resources of the Ashtamudi Lake, a stakeholder council or Village Clam Fishery Council (VCFC) should be formed by the administration. This council should have representation from panchayat, Department of Fisheries, CMFRI, NGO`s working in the area and clam societies. They should meet once in a quarter. The Council should have powers to debate and formulate rules as necessary for effective management of the clam fisheries.

Following the participatory mode 3-tier fishery management system, the VCFC should report to the District Fishery Council (DFC) and ultimately to the State Fishery Council (SFC). The modalities of such a management regime should be enunciated by the DOF.



The southern and northeastern parts of the Ashtamudi Lake are currently devoid of clam populations. It was not so many years ago. This has happened due to deterioration in water quality in these regions through increased urbanization and unregulated waste dumping. This part of the Ashtamudi Lake needs special focus to improve the habitat quality for ecological sustainability of the Lake.

Zones I to V as demarked in the map may be declared as Clam Management Area (CMA) of Ashtamudi Lake by the DOF for the purpose of framing necessary rules and regulations to govern the clam fisheries by the VCFC.

Depuration of clams for hygienic consumption may be encouraged. This could be done by the fishers or processors or agents. A scientific depuration and meat shucking process has been developed by CMFRI and this maybe initially financially supported by the DOF as a scheme.

### **Cephalopod Fishery**

Cephalopods are a marine fishery resource of increasing importance and many species are exploited as by-catch by trawlers from throughout the Indian coast. Although they form only 4-5% of the total marine fish landings, cephalopod stocks are under heavy fishing pressure because of their high value as an exportable commodity. So much so, of late, they are even targeted by the trawl fleet in certain seasons of the year along parts of the west coast of India. The CMFRI has initiated studies on cephalopod stock from Indian waters during the seventies. The initial results of this programme on the taxonomy, biology, fishery and stock assessment of cephalopod stocks pertaining to the seventies were published as a bulletin. Subsequently a major exercise on the stock assessment of Indian cephalopod stocks with data of 1979-89 was made by CMFRI. These studies indicated that squids were exploited at optimum level on both coasts and cuttlefishes were optimally exploited along east coast and under exploited along west coast.

### **Exploited Cephalopods**

Cephalopods exploited from Indian seas can be broadly divided into three, viz., squids (order Teuthoidea), cuttlefishes (order Sepiioidea) and octopuses (order Octopodidea). The dominant species occurring in commercial catches are *Loligo duvauceli*, *Sepia pharaonis*, *S. aculeata* and *Octopus membranaceus*.

### **Methods of Exploitation**

Although about 40% of the world's cephalopod catches are taken by squid jigging and 25% by trawling, in India, cephalopods are principally caught by bottom trawlers operating upto 200m depth zones. While most of the catch is brought in as by-catch from the shrimp and fish trawls employed by the trawlers, of late, there is a targeted fishery for cuttlefishes during the post monsoon period (Sep-Dec) using off bottom high opening trawls along the SW and NW coast. Prior to the seventies traditional gears like shore seines, boat seines, hooks and lines and spearing were the principal gear employed to capture cephalopods.

These traditional gears continue to be used especially for cuttlefishes at Vizhinjam, where there is no trawl fishery. Experimental squid jigging has been tried with Japanese expertise along the west coast by GOI vessels with considerable success. However, commercial squid jigging is not practised in India.

### **Cephalopod Production**

Cephalopod production, which remained at very low level upto the early seventies, has shown a remarkable increase crossing the 100,000 tonne mark in 1994 (Fig.1). From 1973 onwards the commencement of export of frozen cephalopod products to several countries saw the transition of the resource from a discard to a quality resource fetching high foreign exchange. Thereafter its production showed a steep increase (Fig.1). The west coast maritime states, Gujarat (GUJ), Maharashtra (MAH), Goa (GOA), Karnataka (KAR) and Kerala (KER) contribute to the bulk (86%) of the production. While the production from the east coast amounts to only 14%, of which, Tamil Nadu (TN) contributes the maximum followed by Andhra Pradesh (AP). The states of West Bengal (WB), Orissa (OR) and Pondicherry (PON) contribute only a small percentage. Overall, KER ranks first contributing a third of the all India production followed by MAH, GUJ and KAR. At the national level, Jan-Mar and Oct-Dec were the most productive period. Along the upper east and west coast, the above months were the most productive, while in KAR, KER, TN and AP Jul-Sep was also equally productive.

### **Utilization and Marketing**

There is very little internal market demand for cephalopods and consequently almost all the catch is exported. Export of cephalopods from India during 1991 to 2003 is shown in Fig 5. While the quantity peaked in 1995, when cephalopods formed about the 45% of the total quantity exported, the annual average is about 24%. However, the value of cephalopods in total marine exports has remained at 15% from 1992 onwards without much variation. In 2006 the value of cephalopods exported amounted to more than Rs 1000 crores. Category-wise, squid products are the maximum in all years followed by cuttlefish products. The products include dried, frozen whole, filleted, tentacles, rings, roe, wings, IQF and bones and ink. Octopus products exported are meagre, but from 1994 onwards there is rising trend in its exports. The main markets for export of Indian cephalopods are Europe, Japan and China.

Although the quantity exported has remained steady at around 75,000 tonnes, the value has shown a consistent increase in recent years. (Data source: MPEDA,

Cochin) The emergence of cephalopods as an important marine fishery resource of the country with almost cent percent export potential warrants careful monitoring and appropriate management particularly because we are exploiting above the revalidated potential yield of 101,000 tonnes. Several gaps exist in our knowledge of these valuable resources, especially on the life histories of our species. For example, we still have not resolved the question of semelparity of most of our species. At present we know that most Cephalopods constitute an average 24% of total marine exports (range 15-43%) in quantity of the species lay their eggs in the shallow inshore waters. These grounds are subjected to sedimentation due to man-made causes such as dumping of sludge. This might degrade the benthic conditions with a negative impact on cephalopod egg laying and consequently on the recruitment.

### **Gastropod Fishery**

The exploitation of gastropods in India is age-old for both as food and as curios. The famous money cowries used as currency and the religious sentiments attached to the sacred chank are well known. The gastropod biodiversity in Indian waters is very large and no systematic effort has been made to document this qualitatively and quantitatively, apart from few works. Considering the intense exploitation of these shelled animals in certain areas of the country as a raw material for the shell-craft industry, a number of these ornamental molluscs have been declared as endangered and are protected under the Indian Wildlife Protection Act.

### **Chank Fishery**

Chanks (*Xancus pyrum*) are fished mainly for the shell and an organised fishery of considerable magnitude exists along the southeast coast of India. They are also collected at a few other places along the Indian coast. Major chank resources occur in the Gulf of Mannar, particularly along the Ramanathapuram – Tirunelveli coast. Other areas are Thanjavur, South Arcot and Chingelpet in Tamil Nadu, Trivandrum coast in Kerala, the Gulf of Kutch in Gujarat and the Andamans. Unlike pearl oysters, the chanks are regularly fished with few exceptions. The estimated the average annual chank production in India at 12,56,000 chanks comprising 8,77,000 from Tirunelveli coast, 3,00,000 from Ramanathapuram coast, 40,000 from Thanjavur – South Arcot – Chingelpet coast, 22,000 from Kerala state, 12,000 from the Gulf of Kutch and 5,000 from the Andamans. In terms of weight, chank production would be 1250 t/year (see also Figure 3).



### Whelk Fishery

The whelks come under the order Neogastropoda and family Buccinidae. They are mostly carnivorous and scavengers. The meat is edible and the shell is used in the shell craft industries. In India, two species namely, *Babylonia spirata*, and *B. zeylanica* are landed as by-catch, mostly in the bottom trawls. The former species is more abundant and most of the production is exported. Except for some fishery data in the by-catch of shrimp trawls, no information seems to be available on *B. zeylanica*.

### Fishery for ornamental gastropods

There are several economically important species of gastropods which are regularly collected for meat / and or shell. They come under many families, extensively used in shell craft industry and are popularly called as ornamental gastropods. Many of them live in coral reef habitat in regions such as the Gulf of Kutch, Gulf of Mannar, Palk Bay, Andaman and Nicobar Islands and the Lakshadweep group of Islands.

### Future of Molluscan Exploitation

- The following are areas of concern with regard to exploitation of molluscs in India:
- Exploitation of cephalopods above the potential yield estimate and localized over-exploitation of stocks
- Oceanic cephalopod potential to the tune of 20-50,000 t which are yet to be exploited
- Grossly under-reported catches of bivalves and gastropods
- No major studies in the country on bivalve and gastropod biology and no information on the magnitude and economics of the shell-craft industry
- Conservation and stock rebuilding strategies with respect to endangered molluscs are not in place
- In the light of this, it is important to determine the science, management and institutional requirements needed to obtain the tremendous potential value from molluscan resources to the country and to make a path for sustaining molluscan fisheries and rebuilding protected species stocks to realize their long-term potential.

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### **Introduction**

Climate change is predicted to affect individual organisms during all life stages, thereby affecting populations of a species, communities and the functioning of ecosystems. The vulnerability of a species to climate change is generally considered as the extent to which abundance or productivity of species in a region could be impacted by climate change and decadal variability (Hare *et al.*, 2016). Alterations in the fishery and fishery resource profile in turn affect coastal fishing communities dependent on fishing for their livelihood.

Although fishing remains, by and large, the most dominant driver of population abundance, there is now substantial evidence of the impact of climate change and decadal variability on fish and invertebrate populations, with an increasing number of studies linking population models to climate models and projecting future climate change impacts on fish and invertebrate populations (Hare *et al.*, 2016). Long-term climate change is likely to impact the marine environment and its capacity to sustain fish stocks and exacerbate stress on marine fish stocks.

### **Background Information for Zone wise Vulnerability Assessment**

There is ample evidence of the impacts of global climate change on marine environments. Organisms, however, do not respond to approximated global averages. Regional changes are more relevant in the context of ecological response to climate change. Hence, global-scale climate models may be unable to simulate observed changes in temperature and rainfall or the intensification of coastal upwelling in many areas, but regional-scale models may be able to do this (Clark, 2006).

Against the background of changing climate, which we know is a definite happening event, and the paucity of accurate information on the actual changes

that this event induces or can induce in different fish species, there is a large uncertainty hovering over Indian marine fisheries, which already faces the threat of overfishing and pollution impacts. In this context, a detailed study was carried out to assess the vulnerability of key species of fishes and invertebrates likely to impact the fishery in the process of undergoing climate-change induced alterations in phenology, reproductive performance, abundance and distribution.

Vulnerability assessments provide framework for evaluating climate impacts on different species with the aid of existing information and combining the exposure and the sensitivity of a species to a stressor (Hare et al., 2016). Methods for assessing species vulnerability have been described through quantitative approaches developed to examine climate impacts on productivity, abundance and distribution of different species of marine fishes and invertebrates (Hare et al., 2016). The vulnerability study would provide a strong base for evolving strategic fishery management plans for highly vulnerable stocks to counter the likely impacts of a changing climate in the long run.

Assessment of the vulnerability of individual fish and invertebrate species to climate change is a prerequisite to understand or predict changes in the species composition and abundance in a particular region. While it is an established fact that climate change influences the marine environment, distribution and abundance of marine species and their phenology in spatial and temporal scales, the impact of climate change on marine organisms may not be uniform for all species and regions as it depends on the biological and behavioural characteristics of the organisms (Morrison et al., 2015).

For a tropical country like India with wide variations in environmental parameters and a marine fishery which is characteristically multi-species, multi-gear fishery and multi-ground, the criteria which are developed is insufficient to present a true picture of species vulnerability. Therefore following the methodology described in earlier studies, sets of environmental, biological and fishery-based criteria were developed to suitably define the characteristics of tropical Indian species of fishes and invertebrates and their fishery in the region.

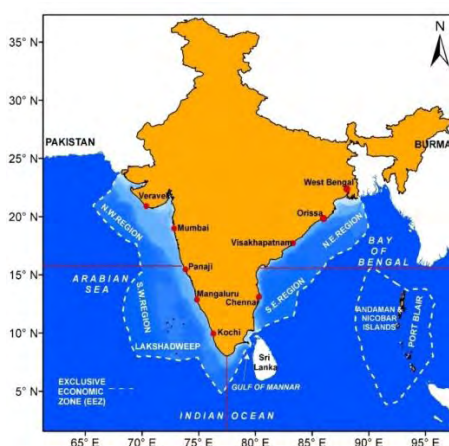
### **Selection of geographical zones for the study**

Peninsular India extends down from the Arabian sea bordering the Gulf of Kutch on the north-west coast upto Cape Comorin overlooking the Indian Ocean at the southern tip of the country and further north along the Coromandel coast

bordering the Bay of Bengal, up to the Sunderbans on the north-east coast of India.

The Indian coast exhibits wide diversity in climatic and oceanic conditions, in terms of temperature ranges, precipitation levels, length of seasons, rainfall, riverine flow, wind patterns, current patterns and coastal upwelling. The wide variation in climatic conditions demands evaluation of zone-wise species vulnerability along the coast.

Based on this, the coast was classified into four different geographical zones viz. north-east (NE), north-west (NW), south-west (SW) and south-east (SE) (Figure 1)



### **Selection of Species**

Preliminary analysis of historical data on fishery showed that there is a wide variation in the species composition and biological responses of the species in different geographical zones. Accordingly about 30 to 36 major commercially important finfishes and shell fishes were selected for the study from each zone, with catch-dependant weighted representation of pelagic, demersal, crustacean and molluscan resources. In all, 68 species were selected, of which many were common to two or more zones and some were characteristic to a particular zone. Thirty two species were selected for the NE coast, 36 for the NW coast and 30 each for the SE and SW coasts. Species selection was done based on abundance of a species in a particular zone, its contribution to the fishery, economic importance, growth and reproductive performance and prey-predator interactions (Table1).

Table 1. Species selected for vulnerability study

| Sl No | Group    | Scientific Name                | Sl No | Group      | Scientific Name                  |
|-------|----------|--------------------------------|-------|------------|----------------------------------|
| 1     | Pelagic  | <i>Chirocentrus dorab</i>      | 35    | Demersal   | <i>Otolithus biauritus</i>       |
| 2     | Pelagic  | <i>Chirocentrus nudus</i>      | 36    | Demersal   | <i>Pampus argenteus</i>          |
| 3     | Pelagic  | <i>Coilia dussumeri</i>        | 37    | Demersal   | <i>Parastromateus niger</i>      |
| 4     | Pelagic  | <i>Coryphaena hippurus</i>     | 38    | Demersal   | <i>Pennahia anea</i>             |
| 5     | Pelagic  | <i>Decapterus russelli</i>     | 39    | Demersal   | <i>Plicofollis dussumieri</i>    |
| 6     | Pelagic  | <i>Encrasicholina devisi</i>   | 40    | Demersal   | <i>Plicofollis tenuispinis</i>   |
| 7     | Pelagic  | <i>Euthynnus affinis</i>       | 41    | Demersal   | <i>Priacanthus hamrur</i>        |
| 8     | Pelagic  | <i>Harpodon nehereus</i>       | 42    | Demersal   | <i>Protonibea diacanthus</i>     |
| 9     | Pelagic  | <i>Katsuwonus pelamis</i>      | 43    | Demersal   | <i>Saurida undosquamis</i>       |
| 10    | Pelagic  | <i>Megalspis cordyla</i>       | 44    | Demersal   | <i>Saurida tumbil</i>            |
| 11    | Pelagic  | <i>Mugil cephalus</i>          | 45    | Demersal   | <i>Scoliodon laticaudus</i>      |
| 12    | Pelagic  | <i>Rastrelliger kanagurta</i>  | 46    | Demersal   | <i>Sphyrna lewini</i>            |
| 13    | Pelagic  | <i>Sardinella fimbriata</i>    | 47    | Demersal   | <i>Upeneus sulphureus</i>        |
| 14    | Pelagic  | <i>Sardinella gibbosa</i>      | 48    | Demersal   | <i>Upeneus vittatus</i>          |
| 15    | Pelagic  | <i>Sardinella longiceps</i>    | 49    | Crustacean | <i>Acetes indicus</i>            |
| 16    | Pelagic  | <i>Scomberomorus commerson</i> | 50    | Crustacean | <i>Charybdis feriata</i>         |
| 17    | Pelagic  | <i>Scomberomorus guttatus</i>  | 51    | Crustacean | <i>Feneropenaeus merguensis</i>  |
| 18    | Pelagic  | <i>Sphyrna jello</i>           | 52    | Crustacean | <i>Metapenaeopsis stridulans</i> |
| 19    | Pelagic  | <i>Sphyrna obtusata</i>        | 53    | Crustacean | <i>Metapenaeus dobsoni</i>       |
| 20    | Pelagic  | <i>Stolephorus indicus</i>     | 54    | Crustacean | <i>Metapenaeus monoceros</i>     |
| 21    | Pelagic  | <i>Tenulosa ilisha</i>         | 55    | Crustacean | <i>Metapenaeus affinis</i>       |
| 22    | Pelagic  | <i>Thunnus tonggol</i>         | 56    | Crustacean | <i>Panulirus polyphagus</i>      |
| 23    | Pelagic  | <i>Thunnus albacares</i>       | 57    | Crustacean | <i>Fenneropenaeus indicus</i>    |
| 24    | Pelagic  | <i>Trichiurus lepturus</i>     | 58    | Crustacean | <i>Penaeus monodon</i>           |
| 25    | Demersal | <i>Carcharhinus limbatus</i>   | 59    | Crustacean | <i>Penaeus semisulcatus</i>      |
| 26    | Demersal | <i>Cynoglossus macrostomus</i> | 60    | Crustacean | <i>Penaeus stylifera</i>         |
| 27    | Demersal | <i>Epinephelus diacanthus</i>  | 61    | Crustacean | <i>Portunus pelagicus</i>        |
| 28    | Demersal | <i>Himantura imbricata</i>     | 62    | Crustacean | <i>Portunus sanguinolentus</i>   |
| 29    | Demersal | <i>Johnius carutta</i>         | 63    | Crustacean | <i>Solenocera crassicornis</i>   |
| 30    | Demersal | <i>Lacatrius lactarius</i>     | 64    | Molluscs   | <i>Perna viridis</i>             |
| 31    | Demersal | <i>Nemipterus japonicus</i>    | 65    | Molluscs   | <i>Sepia aculeata</i>            |

|    |          |                            |    |          |                         |
|----|----------|----------------------------|----|----------|-------------------------|
| 32 | Demersal | <i>Nemipterus randalli</i> | 66 | Molluscs | <i>Sepia pharonis</i>   |
| 33 | Demersal | <i>Otolithes cuvieri</i>   | 67 | Molluscs | <i>Sepiella inermis</i> |
| 34 | Demersal | <i>Otolithes ruber</i>     | 68 | Molluscs | <i>U.(L.) duvauceli</i> |

### Vulnerability Assessment Design

The primary assumption behind the vulnerability assessment methodology used is that current biological performance indices and expected exposure to climate change can be used to evaluate the relative vulnerability of a species (Chin et al., 2010; Johnson and Welch, 2010; Foden et al., 2013; Pearson, 2014; Pecl et al., 2014). While exposure (E) is the projected magnitude of change in the physical environment due to climate variations, and defines the nature and degree to which a species is exposed to climatic variations, sensitivity (S) indicates the extent to which a species is affected due to its life history traits influenced, either adversely or beneficially, by anthropogenic activities, and, adaptive capacity (A) defines the ability (or potential) of a species to adjust successfully to climate or environmental change. In this study, we chose to represent the three components as separate sets of attributes. Based on the attributes, each component was assigned a score. The Vulnerability (V) was then estimated from the relation:

$$V = (E+S) - A$$

### Exposure attributes and their scoring

Exposure attributes used are those climatic variables which could impact the biological or behavioural characteristics of the selected species. Out of several environmental parameters initially considered for inclusion under exposure attributes, 6 environmental parameters viz., sea surface temperature (SST), rainfall, current speed, current direction, upwelling index and chlorophyll concentration, were selected for as exposure attributes.

### Sensitivity attributes and their scoring

For sensitivity attributes, the biological characteristics of species that are indicative of their ability or inability to respond to environmental changes and exploitation/fishery related pressures are used. For this study 9 attributes were selected based on time series data for a period 40 years (1975- 2015) on fishery and biology of each species extracted from published information available in CMFRI repository (eprints@cmfri). Data collected through detailed biological study done during 2011-2015 in different zones under the NICRA project was also used. The sensitivity attributes considered were Fecundity, Complexity in

early development, Growth coefficient, Trophic level, Longevity/Life span, Lc/Lm, Anomaly in CPUE, Exploitation rate, Price etc. (Table 2)

Table 2. Criteria developed for vulnerability assessment

| Environmental criteria            | Biological criteria             | Fishery related criteria |
|-----------------------------------|---------------------------------|--------------------------|
| Sea surface Temperature           | Fecundity                       | Anomaly in CPUE*         |
| Rainfall                          | Complexity in early development | Exploitation rate        |
| Ocean current Speed               | Growth coefficient              | Price                    |
| Ocean current direction (S to N)* | Trophic level                   | Gear                     |
| Coastal upwelling index           | Longevity/Life span             |                          |
| Chlorophyll concentration         | Lc/Lm                           |                          |
|                                   | Horizontal distribution         |                          |
|                                   | Duration of spawning            |                          |
|                                   | Prey specificity                |                          |

### Adaptive Capacity attributes and their scoring

Adaptive capacity attributes used are primarily biological and ecological traits that could help the species to adapt to a fluctuating or changing environment. Four attributes were selected for this study. Based on expert opinion for each attribute the scoring was limited to a scale of 1-3, representing low, medium and high. The adaptive capacity attributes were Horizontal distribution, Vertical Distribution, Duration of spawning, Prey specificity/No. of prey groups/Niche breadth (Fish base) etc.

### Vulnerability assessment

The sum of exposure and sensitivity is the impact. For preparation of vulnerability matrix, climatic variables (exposure attributes) were given more weightage as the sensitivity traits are dependent on changes in the climatic variables. Accordingly the following combinations of exposure and sensitivity scores were fixed as binding (Fig 3)

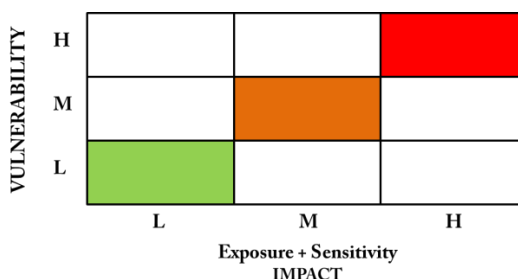


Figure 2. Impact versus vulnerability matrix



### **Species vulnerable to climate change**

Species vulnerability study in relation to climate change was carried out for 68 commercially important shellfishes and finfishes along the coast of India. The species studied belonged to different realms in the water column, and could be classified as pelagic, bentho-pelagic, demersal and benthic. There is considerable variation in the distribution of adults and juveniles of the same species within the water column. The biology of the species was also diverse on many counts. Some species had wide distribution (seerfishes, ribbonfishes, mackerel sardine, lizardfishes, shrimps, cephalopods) and some had restricted distribution (Bombay duck, some species of croakers, and shrimps). Most of the species were broadcast spawners with pelagic eggs and larvae, and occupied a range of trophic levels. Of the 68 species, 3 species are elasmobranchs, 45 are teleosts, 15 crustaceans and 5 molluscs. One of the mollusc species *Perna viridis* is sedentary in nature.

### **Climate vulnerability**

Increasing temperature was the most important driver in climate change. There was zone-wise differentiation in the exposure range for climatic variabilities. Except for the north-east zone the ranking tended towards moderate vulnerability, with a scoring range of 1.33-1.73. In the north-east zone the range was 1.66-2.21. The anomalies of climate variables were high along the north-east and north-west zone, whereas they were moderate in the other zones. Temperature anomalies were high along the north-east and south-east zones. Climate exposure ranking of pelagic species was comparatively higher than that of demersal species.

### **Impact on the species**

Ranking of impact, an additive index of exposure and sensitivity attributes, was classified into high, medium and low for the 68 species assessed for vulnerability. There was zonal variation in the dispersion of species with respect to sensitivity and climatic vulnerability (Exposure). Mean sea surface temperature (SST) anomalies, mean upwelling index, current speed and current direction were considered to be important factors in climatic variability score. The climatic variability score was medium in all the zones. The exposure and sensitivity attributes scored high for some species in north-east.

About 83% of the pelagic fishes studied were highly vulnerable, followed by demersal fishes (66 %), molluscs (60%) and crustaceans (53%).

**Table 3** Zone wise list of species which are highly vulnerable

| Zone  | Species  |
|---|--|
| North-West<br>Zone-11<br>P- 4, D-5, C-1, M-1  | <i>Coilia dussumeri</i> , <i>Decapterus russelli</i> , <i>Harpodon nehereus</i> , <i>Thunnus tonggol</i> , <i>Epinephelus diacanthus</i> , <i>Otolithus biauritus</i> <i>Pampus argenteus</i> , <i>Parastromateus niger</i> , <i>Protonibea diacanthus</i> , <i>Acetes indicus</i> , <i>Sepia pharonis</i>   |
| South-West<br>Zone-10<br>P-1, D-5, C-3, M-1   | <i>Rastrelliger kanagurta</i> , <i>Carcharhinus limbatus</i> , <i>Parastromateus niger</i> <i>Plicofollis tenuispinis</i> , <i>Sphyrna lewini</i> , <i>Upeneus sulphureus</i> , <i>Metapenaeus dobsoni</i> , <i>Metapenaeus monoceros</i> , <i>Fenneropenaeus indicus</i> , <i>Perna viridis</i>   |
| South- East<br>Zone-23<br>P-11, D-7, C-4, M-1 | <i>Chirocentrus dorab</i> , <i>Chirocentrus nudus</i> , <i>Decapterus russelli</i> , <i>Euthynnus affinis</i> , <i>Katsuwonus pelamis</i> , <i>Sardinella gibbosa</i> , <i>Scomberomorus commerson</i> , <i>Sphyrna jello</i> , <i>Stolephorus indicus</i> , <i>Thunnus albacares</i> <i>Trichiurus lepturus</i> , <i>Carcharhinus limbatus</i> , <i>Cynoglossus macrostomus</i> <i>Nemipterus japonicus</i> , <i>Pampus argenteus</i> , <i>Parastromateus niger</i> , <i>Saurida undosquamis</i> , <i>Saurida tumbil</i> , <i>Metapenaeus Monoceros</i> , <i>Penaeus monodon</i> , <i>Portunus pelagicus</i> , <i>Portunus sanguinolentus</i> , U.(L.) <i>duvauceli</i> |
| North-East<br>Zone-22<br>P-11, D-8, C-3       | <i>Coryphaena hippurus</i> , <i>Katsuwonus pelamis</i> , <i>Megalaspis cordyla</i> , <i>Sardinella fimbriata</i> , <i>Sardinella gibbosa</i> , <i>Sardinella longiceps</i> , <i>Scomberomorus commerson</i> , <i>Scomberomorus guttatus</i> , <i>Sphyrna jello</i> , <i>Thunnus albacares</i> <i>Trichiurus lepturus</i> , <i>Nemipterus japonicus</i> , <i>Nemipterus randalli</i> , <i>Otolithes ruber</i> , <i>Plicofollis tenuispinis</i> , <i>Saurida undosquamis</i> , <i>Saurida tumbil</i> , <i>Upeneus sulphureus</i> , <i>Upeneus vittatus</i> , <i>Metapenaeus monoceros</i> , <i>Fenneropenaeus indicus</i> , <i>Penaeus monodon</i> .                       |

**Table 4 - List of species with high vulnerability in two or more zones**

| Species               | Zones      | No of zones | Major influencing factor               | Major gear |
|-----------------------|------------|-------------|--|------------|
| <i>M. monoceros</i>   | SW, SE, NE | 3           | Life history and fishing pressure      | Trawl      |
| <i>P. niger</i>       | NW, SW, SE | 3           | Fishing pressure (juvenile)            | Trawl      |
| <i>P. tenuispinis</i> | SW, SE, NE | 3           | Life history and fishing pressure      | Trawl      |
| <i>C. limbatus</i>    | SW, SE     | 2           | Life history                           | Trawl      |
| <i>D. russelli</i>    | NW, SE     | 2           | Fishing pressure                       | Trawl      |
| <i>F. indicus</i>     | SW, NE     | 2           | Life history and fishing pressure      | Trawl      |
| <i>K. pelamis</i>     | SE, NE     | 2           | Life history and fishing pressure      |            |
| <i>N. japonicus</i>   | SE, NE     | 2           | Fishing pressure                       | Trawl      |
| <i>P. monodon</i>     | SE, NE     | 2           | Life history and fishing pressure      | Trawl      |
| <i>S. gibbosa</i>     | SE, NE     | 2           | Fishing pressure and lack of upwelling |            |
| <i>S. tumbil</i>      | SE, NE     | 2           | Fishing pressure                       | Trawl      |
| <i>S. undosquamis</i> | SE, NE     | 2           | Fishing pressure                       | Trawl      |

|                     |       |   |                                   |       |
|---------------------|-------|---|-----------------------------------|-------|
| <i>S. commerson</i> | SE,NE | 2 | Fishing pressure                  |       |
| <i>S. jello</i>     | SE,NE | 2 | Fishing pressure                  | Trawl |
| <i>T. albacares</i> | SE,NE | 2 | Life history and fishing pressure |       |
| <i>T. lepturus</i>  | SE,NE | 2 | Fishing pressure                  | Trawl |

Vulnerability assessment of fish stocks to climate change indicates that the finfishes and shellfishes along the Indian coast are highly or moderately vulnerable to climate change. The species composition and exposure of the same species in different zones are variable and the study shows the extent to which abundance or productivity of a species could be impacted by climate change. In contrast to the influence of exposure factors, the influence of sensitivity attributes was more pronounced, indicating the diversity of species composition of the resources exploited along the Indian coast. Changes in species composition of the exploited resources in four different zones have been observed in this study and the changes are likely to continue in the future also.

The present study shows that fishing pressure is playing a key role in making the species vulnerable in different zones as the climatic variables and sensitivity traits influencing the species could not be changed. The primary approach towards mitigation must consider the vulnerability of a species as dependent on fishing pressure as much as on climate variations. In the context of the present study, mitigation would mean directly managing the fishery of different species, singly, wherever possible, or within the limitations of a mixed fishery, as will be the case in India's marine fishery. Fortunately, several species that contribute in major to the marine fish landings in India are highly resilient with good bounce-back potential due to their inherent reproductive and growth efficiencies. India's oil sardine fishery and threadfin bream fishery are good examples of this. This study was aimed to provide a broad assessment of vulnerability of fishes and shell fishes due to climate change along the Indian coast and the results will act as an effective tool in understanding the species to be prioritized zone wise and the extent to which management must be done.

This assessment will help in adding a climate change perspective to management measures. Furthermore, the assessment of the resources would help the fisheries managers in formulating policy related to the sustainable exploitation of the resources with special attention to the species which are highly vulnerable in each zone. Efforts to reduce the fishing mortalities of the vulnerable species could be initiated. The assessment would contribute to the development of region specific ecosystem based fisheries management and it

would be useful for identification of species-specific mitigation measures in relation to climate change. The present vulnerability ranking of the species in different zones will be a handy tool to conserve the species which are ranked as highly vulnerable and also which tend to move to high vulnerability category, through policy level interventions.

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### **Introduction**

Fisheries support the world for the food, nutrition and employment of millions of people, many of whom struggle to maintain reasonable livelihoods. The total world fish production in 2016 reached an all-time high of 171 million tonnes, of which 88% was utilized for direct human consumption, owing to relatively stable capture fisheries production (FAO, 2018). Estimates by the Food and Agricultural Organisation indicates that capture fisheries employ over 27 million people worldwide, of which 85% live in Asia. Marine fisheries play an important role in food security and nutrition in developing countries. There is serious concern about the state of marine fisheries worldwide. While over-fishing is likely to have been the major cause of the serious setbacks, these have probably been exacerbated by habitat degradation. Fisheries sector plays an important role in the overall socio-economic development of India. The fisheries sector contributed 76,913 crores to the GDP during 2009-10 which is 0.96 per cent of the total GDP at factor cost and 5.4 per cent of the GDP at factor cost from agriculture forestry and fishing (Zacharia and Najmudeen, 2013). During 2015-16, the export of marine products from India reached over 9.45 lakh tonnes valued at Rs. 30,421 crores and US\$ 4.688 billion (MPEDA, 2017). India is one of major fish producing countries in the world contributing over 3 per cent of both marine and freshwater fishes to the world production with third position in capture fisheries and second in aquaculture.

The marine fishes, based on their depth-wise distribution may be grouped mainly as pelagic and demersal, the former occupying surface and subsurface waters and the latter the neretic areas in the continental shelf. Demersal fishes can be divided into two main types: Strictly benthic fish which can rest on the

sea floor, and benthopelagic fish which can float in the water column just above the sea floor.

Benthic fish, sometimes called groundfish, are denser than water, so they can rest on the sea floor. Benthic fish which can bury themselves include dragonets, flatfish and stingrays. Demersal finfishes are one of the major components in the marine fish landings along the Indian coast. The major gear which exploit the demersal finfish resources in India are bottom trawlnets. Demersal fish though generally occupy the seafloor; feeding on the benthic organisms and detritus, perform vertical and horizontal migration in search of their feeding and breeding grounds. Hence, the day and night catches in bottom trawl show differences, eg. catfish, rays, eels etc. In the inshore fishing activities below 50 m depth, occurrence of pelagics in bottom trawl and catfish, perches and penaeid prawns in pelagic net is common. Trawl catch consists of 76% demersal (finfish 38% and invertebrates -38%) remaining pelagic or column water fishes.

When compared to the pelagic resources, proper exploitation of the demersal finfishes in India has been initiated only three decades ago (Bensam, 1992). With the introduction of mechanized bottom trawling from the late fifties, the exploitation of demersal finfishes attained a 2.7- fold increase during late eighties. With the large-scale introduction of mechanized trawling, several environmental problems and stock-recruitment hazards to inshore fisheries have come up. Demersal fish groups such as the sharks, groupers, snappers, threadfins, pomfrets and Indian halibut are commercially valuable and contribute substantially to the economy of Indian marine fisheries. Some of these groups, especially of large-size, are targeted by the fishermen by using different craft and gear combinations. However, several other demersal finfishes are not targeted, but are landed as bycatch by shrimp trawlers (Vivekanandan, 2011). Recent changes in the ecosystem due to climate change coupled with intensive fishing pressure necessitates the formulation of policy measures to harvest the demersal fishery resources of the country at sustainable levels.

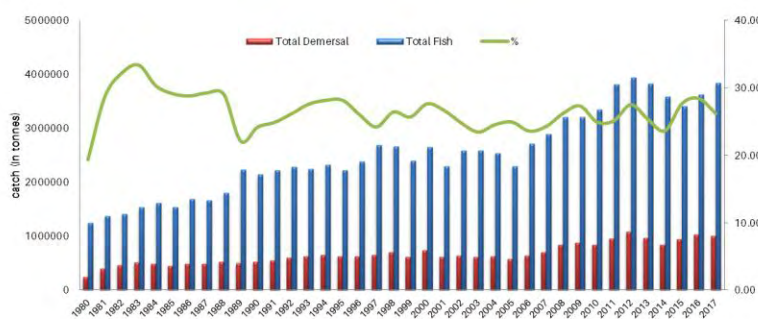


Figure 1. Trends in the landings of demersal finfishes in India during 1980-2017.

The landings of demersal finfishes India during 1980-2014 period shows that the catch is increasing steadily over the years from a meagre of 2,34,408 tonnes to nearly 10,76,789 tonnes in 2012, and thereafter declined to 8,42,199 tonnes in 2014. However, the catch share of demersal finfishes during the last 35 years indicates that the contribution of demersal finfishes to the total Indian marine landings is decreasing over the years. The maximum share was reported in 1983 with 33% contribution and the lowest share (21.7%) was in 1989. The region-wise average share of demersal finfishes along the Indian coast shows that the northwest region comprising of Gujarat and Maharashtra contributes the highest share, followed by southwest coast comprising Kerala and Karnataka and southeast coast comprising Tamil Nadu and Andhra Pradesh. The share of demersal finfishes to all India marine landings of India in 2017 was 26%.

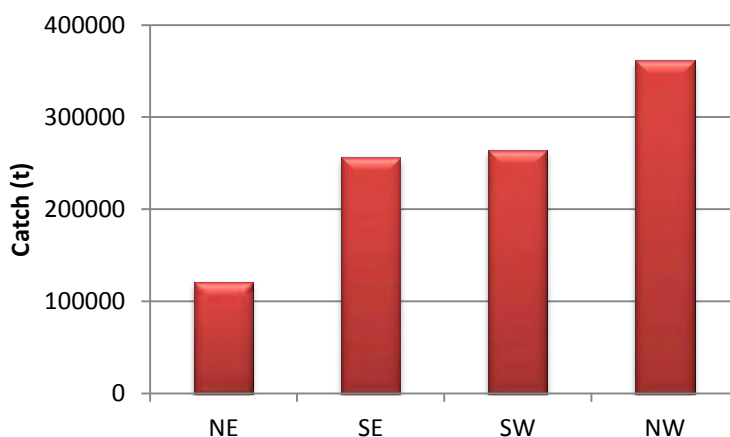


Figure 2. Region-wise landings of demersal finfishes during 2017.

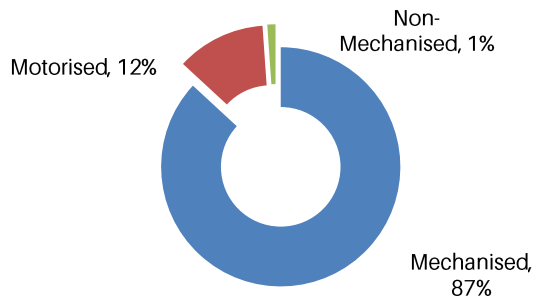


Figure 3. Sector-wise landings of demersal finfishes for the period 2007 - 2012.

The group wise composition of demersal finfish assemblages in Indian marine fish landings during 2016 indicate that the major contributors are the other perches including bulls eye (23%), followed by threadin breams (19%), croakers (18%), silverbellies and catfishes contributed 11% each, lizardfishes (7%) rock codes (6%) and soles (5%). The exploitation status of the important groups of demersal finfishes along the coast of India are briefly given below.

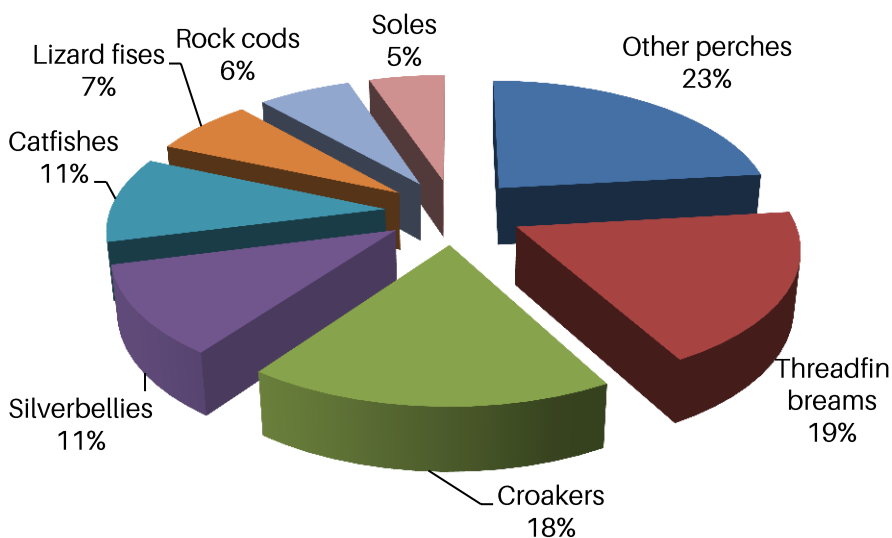


Figure 4. Demersal finfish composition in the marine fish landings of India during 2017

### Elasmobranchs

In India, there are about 110 species of elasmobranchs, of which 66 species of sharks, 4 sawfishes, 8 guitarfishes and 32 species of rays are landed in the



commercial catches. Among these, 34 species are commercially important. Some species of elasmobranchs are protected under the Wildlife Protection Act (10 species), which include, *Pristis microdon*, *Rhynchobatus djiddensis*, *Pristis zijsron*, *Carcharhinus hemiodon* (Pondicherry shark), *Glyphis glyphis*, *Rhincodon typus* (whale shark), *Urogymnus asperrimus* (Porcupine ray). Majority of the species of elasmobranchs in the Indian seas are viviparous, some are oviparous and few are ovo-viviparous with very low fecundity. All India landings of elasmobranchs during 2013-17 was 48,735 tonnes, forms 6% of demersal catch. Trawl nets accounting for 48.8%, gillnets 35.6% and hook & line units 6% of the total elasmobranch landings of the country.

**Sharks:** Average annual shark landings in India during 2013-17 was 21,998 tonnes, which formed 45% of the total elasmobranch landings of the country. The major families appeared in the landings were Carcharhinidae, Triakidae, Sphyrnidae, Echinorhinidae, Hemiscylliidae, Alopiidae, Lamnidae, Centrophoridae, Squalidae and Stegostomatidae. The dominant species in the landings were *Carcharhinus falciformis* (37.25%), *Alopias superciliosus* (11.85%), *Sphyrna lewini* (11.53%), and *Alopias pelagicus* (8.53%). Most of the catch was contributed by multiday trawl nets (34%) followed by mechanised gillnet units (27%).



Figure 5. Heavy landings of sharks and rays at Cochin Fisheries Harbour, Kerala coast

**Rays:** The landing of rays in India during 2016 was 26,211 tonnes, which formed 51% of the total elasmobranch landings of the country. The major families in the landings were Dasyatidae, Mobulidae, Myliobatidae, Gymnuridae and Rhinopteridae

**Skates/guitar fishes:** All India landings of guitarfishes were estimated at 3627 tonnes, which constituted 4% of the total elasmobranch landings of the country. The major families of guitarfishes landed along the coast are Rhinidae and Rhinobatidae.

There are significant changes in the share of sharks and rays to total elasmobranch landings recent years. The all India Production Elasmobranchs during 1999-2010, shows that sharks were dominant in the catch with 49.7% share and that of the rays was 44.5%. However, the landings during 2013-17 indicate that the rays has emerged as the dominant group with 48% followed by sharks with 45% share.

Sharks are crucial to marine ecosystems. They maintain a balance in populations of prey species. They are in a global decline. Overfishing & Life history parameters has reduced many shark populations. Life history traits that make sharks vulnerable group of fishes. The shark's reproductive strategy is very different to most bony ocean fish that release millions of eggs in a lifetime. Long time to reach sexual maturity - dusky shark can take more than 20 years to reach sexual maturity and sharks have long gestation periods (one to two years). They have a small number of offspring (pups). Most shark species give birth to between 2 and 20 pups after a pregnancy of 8-12 months. They breed only every second or third year Females of many shark species rest between breeding cycles for at least one year. Most of the shark species have a tendency to form groups based on their age, sex and/or maturity. India is the second largest shark fishing nations of the world after Indonesia. Conservation and management measures for shark species are initiated in India. Already 10 elasmobranch species are protected in India under Wildlife Protection Act. There is a blanket ban on the export of shark fins from India. Unlike many other countries, the sharks are landed 'fin on' in India and there is a great demand for shark meat in the local markets in many parts of the country.

### **Perches**

This group was abundant in the rocky grounds off Kerala and Tamil Nadu and was exploited by drift nets, hooks and lines and traps. All India annual average landings of Perches during 2013-17 is 3.50 lakh tonnes and forms 36% of total demersal finfish landings. Among the different groups of perches landed along

the Indian coast, threadfin breams were the dominant group with 47% of the total perch landings, followed by other perches mainly composed of bull's eyes belonging to the family priacanthidae with 34% share, rock codes/groupers 12%, pigface breams 4% and snappers contributed 3% to the total annual catch.

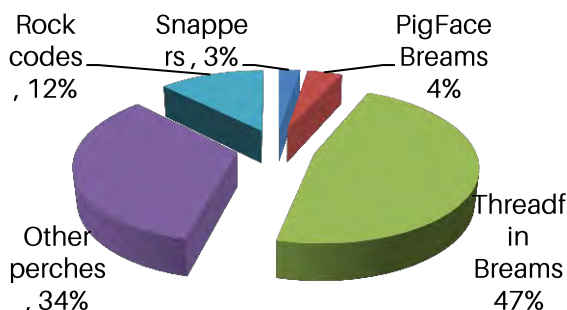


Figure 6. Composition of different groups to the total perch landings in India

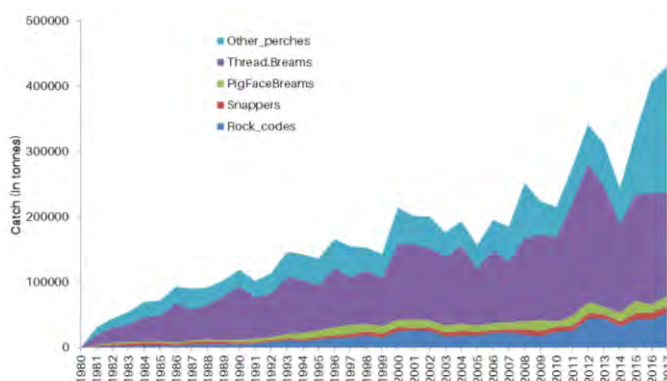


Figure 7. Trend in the landings of perches in India during 2013-2017

### Threadfin Breams

Six species of threadfinbreams are known from the seas around India. *Nemipterus japonicus*, *N. randalli*, *N. bipunctatus*, *N. metopias*, *N. zysron*, *N. nematophorus*, *N. tolu*. Among these, *Nemipterus japonicus*, *N. randalli* are commercially important. Their abundance is influenced by upwelling and is known to move to inshore waters during monsoon period along the west coast. They are fractional spawners with protracted spawning periods. Spawning in *N. japonicus* takes place during October-April with a peak during October- December along Gujarat. In Kerala, *N. japonicus* and *N. randalli* spawn during monsoon and post monsoon periods with peaks during monsoon in the former and during post monsoon in the latter species. All India annual average landings of threadfin

breams during 2013-17 was 1.62 lakh tonnes, forms 17% of the total demersal finfish catch in India.

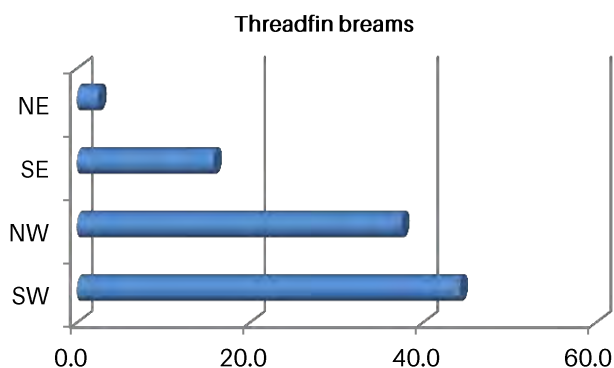


Figure 8. Region wise landings of threadfin breams in India during 2013-17

## Groupers

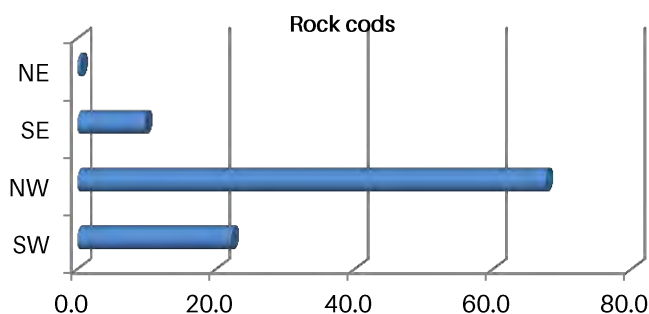


Figure 9. Region wise landings of groupers in India during 2013-17

Rock cods or groupers are protogynous hermaphrodites, initially maturing as females then reverting to males as they grow in age and size. The major species observed in the landings are *Epinephelus chlorostigma*, *E. diacanthus*, *E. areolatus*, *E. tauvina*, *E. morrhua*, *E. bleekeri*, *E. longispinnis*, *Cephalopholis argus*, *Aetheloperca rogaa*, *Variola louti*. The annual landings of groupers during 2013-17 in India was 43,156 tonnes, which formed 4.5% of the demersal finfish landings of India. North-west coast comprising Gujarat and Maharashtra dominate in the catch with 68% of the total grouper landings of the country.

## Snappers

The major species observed in the all India landings of snappers were *Pristipomoides typus*, *L. argentimaculatus*, *Lutjanus gibbus*, *L. rivulatus*, *L. bohar*, and *L. lutjanus*. The annual catch of snappers during 2013-17 in India was 8,893 tonnes. Southeast coast of India contributed the majority of landings of snappers in India with 63% followed by northwest coast of India.

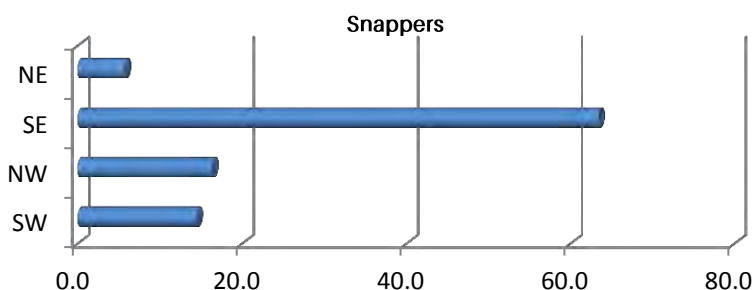


Figure 10a. Region wise distribution of snappers in India



Figure 10b. Snapper Landings in India

## Bull's Eyes

The annual landings of Bullseyes during 2016 in India was 130740 tonnes, which formed 32% of the total perch landings of the country. They belong to a single family Priacanthidae. The major species observed in the landings are *Priacanthus hamrur*, *Oookeolus japonicus* and *Priacanthus Sagittarius*. From a mere 43,576 tonnes in 2015 its landings of bullseye has been escalated to a three- times-high of 1.3 lakh tonnes during 2016.



Figure 11. Catch of Bullseye, *Priacanthus* sp. and Emperor bream/ pigface bream

### Pigface Breams

The major species observed in the landings of pigface breams/ emperor breams in India are *Lethrinus mahsena*, *L. lentjan*, *L. conchylatus*, *L. nebulosus*, *L. ramak*, *L. elongatus* and *Lethrinus miniatus*. The landings of Pigface breams in India during 2017 was 14,492 t, which formed about 1.5% of the total demersal landings of the country. Southeast coast of India contributed the major share of landings of pigface breams in India.

### Lizardfishes

All India landings of lizardfishes are 68,329 tonnes, forms 7% of demersal catch 20 - 40 m depth up to 150-200 m depth. The species of lizardfishes landed along the west coast of India are *Saurida tumbil*, *S. undosquamis*, *Trachinocephalus myops*, *Synodus englemani* and that of East coast are *Saurida undosquamis*, *S. longimanus* and *S. micropectoralis*, *Saurida tumbil*, *Trachinocephalus myops*,



*Synodus englemani*. Spawning in *S. tumbil* occurs during September to March off Veraval and Bombay along North west coast; August to November off Cochin.



Figure 12. Lizardfish landings along the west coast of India

### **Catfishes**

Catfishes are important demersal resources which have wide distributional range in the Indo-Pacific region. They are distributed all along the Indian coastal waters upto the middle shelf with preferential concentration on muddy grounds of 30-70 m depths. Catfishes migrate both vertically (diurnal migration) and horizontally (seasonal) in small schools to large shoals in response to seasonal climatic / hydrographic variations. Marine catfishes belong to the family Ariidae, of which 11 species appear in the commercial fisheries.



Figure 13. Catfish landings along the west coast of India

West coast of India landed 70% of the total catfish catch and the east coast 30%, northwest coast landed 90% of the west coast catch. All species of catfishes exhibit parental care - the male carrying the brood (25-120 eggs) in the oro-buccal cavity for 1 to 2 months' time until the juveniles (4-7 cm) are released. After spawning the brooding males segregate into shoals and move along the surface and prefer shallow water. The newly released juveniles of all species of tachysurids live in the shallow muddy grounds feeding on the bottom epi-and in-fauna - become easy target in fishing. The all India landings of catfishes is during 2016 was estimated at 80700 tonnes, which formed 8.4% of demersal finfish catch of India. Nearly 50% of the catch was from north west coast of India.

### Flatfishes

These were abundant in muddy and/or sandy bottom up to about 80 m depth belonging to genera such as *Cynoglossus*, *Psettodes*, *Pseudorhombus*, *Bothus*, *Paraplagusia*, etc. and exploited by trawl nets, gill nets and other artisanal gears. The Commercial exploitation of flatfishes along the Indian coast varies widely with *Cynoglossus macrostomus* dominating in the West Coast and *Cynoglossus macrolepidotus* along the East coast. The Fishery of *Psettodes erumei* showed a decline in recent years. The all India landings of flatfishes during 2013-17 was 44,354 tonnes, which formed 4.6% of demersal finfish catch of India. Bulk of the landings of soles are contributed by northwest coast followed by southwest coast

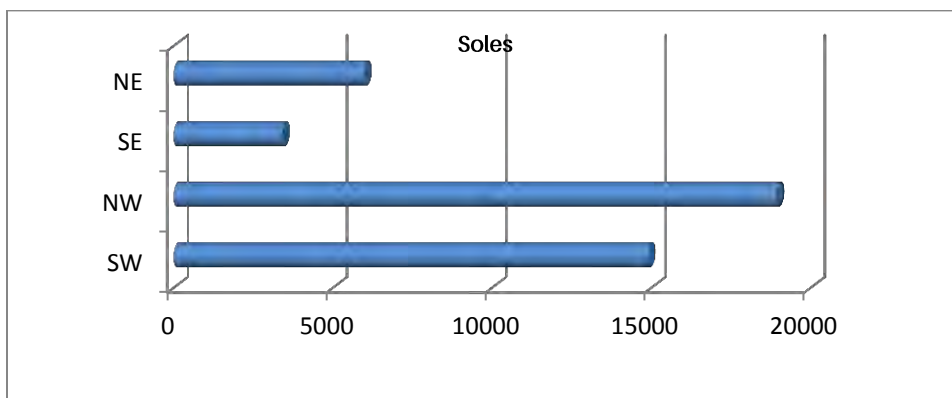


Figure 14a. Region wise distribution of soles in India





Figure. 14b. Landings of flatfishes

### Sciaenids

Scienids include high value demersal resources like croakers, which are landed mainly from Gujarat and Maharashtra. The important gears used are trawls and gill nets. These fishes are caught mainly during October - December and January - March. They mainly consist of the species like *Pseudosciaena diacanthus*, *Otolithes* spp. and *Johneios* spp. *Protonibea diacanthus*, *Johniops macrorhynus*, *Otolithes cuvieri*, *J. dussumieri*, *J. glaucus*, and *O. ruber*. All India annual landings of Sciaenids during 2013-17 is 1, 61,177 tonnes, which formed 16.8% of demersal finfish catch of the country. Northwest region is the highest contributor followed by northeast region.

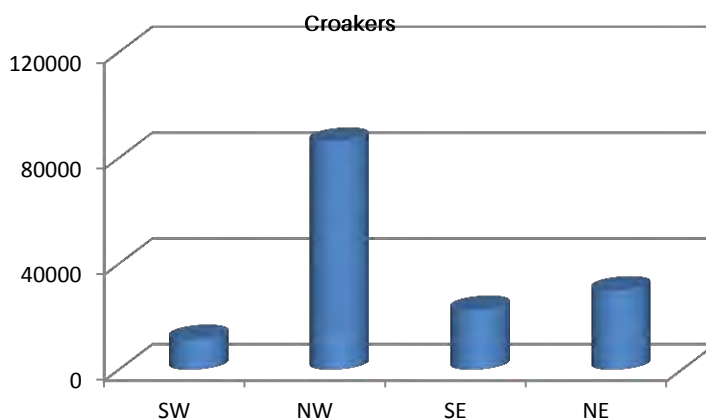


Figure 15. Region wise distribution of croakers along the Indian coast

## Pomfrets

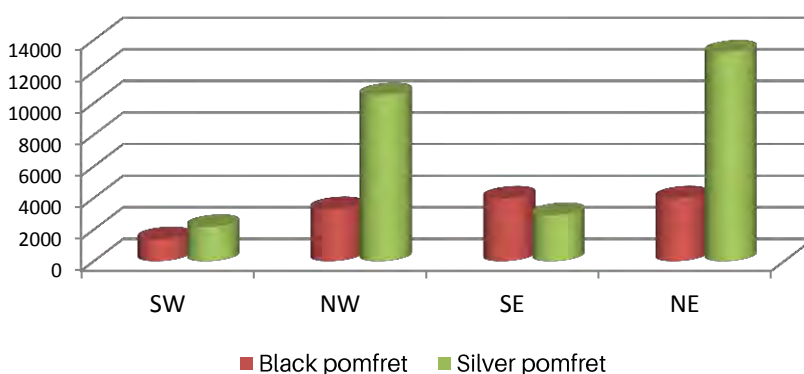


Figure 16. Region wise distribution of pomfrets along the Indian coast

Pomfrets belong to two families, the black pomfret *Parastromateus niger* is coming under the family Carangidae and the silver pomfret *Pampus argenteus* belongs to the family Stromateidae. They are landed abundantly in Gujarat and Maharashtra. The black pomfret landings in India during 2013-17 was 15,400 tonnes, and that of silver pomfret was 27,800 tonnes, which formed 3.3% of demersal finfish catch of the country.



Figure 17. Black pomfret *Parastromateus niger* and the Silver pomfret *Pampus argenteus*

## Silverbellies

Silverbellies belonging to the family Leiognathidae. Exploited by trawl nets and anisandal gears, this group formed about 11% of demersal finfish production. The major species landed along the coast of India are *Leiognathus splendens*, *L.*

*equlus*, *Gazza minuta*, *L. bindus*, *L. dussumieri*, *L. jonesi*, *Secutor insidiator*. All India annual landings of silverbellies was 1, 08,200 tonnes, which formed 11% of demersal finfish catch of India and most of the catch is contributed by southeast coast of India.

### Whitefish

This resource is also called buttefish and known to be depleted or overexploited by the mechanised trawl operations along the near-shore waters of west coast of India. Although distributed all along the coastline, it has been supporting notable fisheries along the southwest and southeast regions. All India landings of whitefish is 6,260 tonnes, forms 0.7% of demersal catch *Lactarius lactarius* is the only species available in this family. Whitefish production in India shows wide fluctuation. Shows steady fall except spurt in 1983 and 1985. In Karnataka it fluctuated between a low of 37 t in 1964 and highest of 2,930 t in 1988. East coast shows a steady decline from 4,738 t in 1960-69 to 8,88 t in 1990-99. West coast showed an increase from 2,901 t in 1960-69 to 12,354 t in 1980-89 then steep decline to 6,109 in 1990-99.



Figure 18. Whitefish *Lactarius lactarius* landings along the coast of India

### Goatfishes

This group has three important genera in India, *Upeneus*, *Parupeneus* and *Mulloidichthys*. These were exploited by trawls and traditional gears mostly in Tamil Nadu, Andhra Pradesh, Kerala, Kamataka and Maharashtra. Dominant species along the east coast of India include *Upneus taenipterus*, *Upeneus bensasi*, *Upenues sulphureus*, *Upeneus sundaicus*, *Parupenus indicus* and *U. molluccensis*. All India landings of goatfishes during 2016 was 30,276 tonnes, which formed 3.2% of demersal finfish catch of the country.



Figure 19. Goatfish landings along the coast of India

### Eels

Eels are long-bodied, snake like fishes, having a crevice dwelling or sediment-burrowing mode of life, though some live in the pelagic realm of the open oceans. Traditionally marketable species of eels are caught from conventional fishing grounds of northwest and northeast coasts of India and are largely a by-catch. Pike congers belonging to the family Muraenesocidae occur in tropical waters in the soft bottoms upto 100 m depth and in estuaries. Four species are recorded in Indian waters and they grow to a maximum length of 80 cm (*Congresox talabon*) (Cuvier, 1829), 250 cm (*C. talabonoidies*) (Sleeker, 1853), 180 cm (*Muraenesox bagio*) (Hamilton-Buchanan) and of 80 cm (*M. cinereus*) (Forsskal, 1775).



Figure 20. Eels belonging to the family Muraenesocidae landed along the Kerala coast

### **Regionwise Distribution of Species**

Finfishes exploited by trawls belong to 21 major fish groups, which are mostly demersal groups. Each maritime region of India is characterized by dominance of specific demersal finfish groups. Along the northeast (NE) coast, sciaenids, catfishes and pomfrets (74.0% to the demersal landings) are dominant. The southeast coast is characterised by the abundant landings of silverbellies and pigface breems. Along the southwest coast of India, threadfin breems and other perches are the major demersal resources and the northwest coast is characterised by the dominance of sciaenids, catfish, pomfrets and threadfin breems.

### **Existing Management Practices**

**Seasonal closure of fishery:** The regulations for "closed season were notified for the Eastern Arabian Sea from 1988 onwards.

**Mesh size regulation and Minimum Legal Size:** Minimum mesh size for different species was recommended for avoiding juvenile bycatch. Square mesh size of 40 mm showed that it provides better opportunity for the juveniles to escape and it is recommended for cod end of trawls. Minimum Legal Size (MLS) for 58 species of finfishes and shellfishes including demersal finfishes have recommended by the Central Marine Fisheries Research Institute which have been enacted by Gazette notification by Govt. of Kerala.

**Restriction of fishing areas:** In the context of persistent conflicts between artisanal and mechanized vessels in the inshore waters. Under this act, the trawl boats have been banned from fishing in inshore areas, which have been assigned exclusively to the artisanal craft. Community participation in the formulation of the management actions are yielding good results in some parts of the country.

**Protected species and Marine Protected Areas (MPAs):** Several species are protected under Wildlife Protection (1971) Act. Capture or trade on these species is prohibited under the act. Releasing sharks after finning is prohibited under a notification. Under this act, fishing for whale shark is prohibited. There are 31 MPAs along India's coastline that have been officially declared for conserving and protecting coastal and marine biodiversity (SCBD, 2006)

Table 1. Minimum Legal Size (MLS) recommendations for the selected demersal finfish species in the fishery along the coast of Kerala.

| S.No. | Species Name                   | Common Name              | Recommended MLS (cm) |
|-------|--------------------------------|--------------------------|----------------------|
| 1.    | <i>Cynoglossus macrostomus</i> | Malabar sole             | 9 TL                 |
| 2.    | <i>Saurida tumbil</i>          | Lizardfish               | 17 TL                |
| 3.    | <i>Johnius sina</i>            | Croaker                  | 11 TL                |
| 4.    | <i>Nemipterus japonicus</i>    | Threadfin bream (Yellow) | 12 TL                |
| 5.    | <i>Lactarius lactarius</i>     | White fish               | 10 TL                |
| 6.    | <i>Nemipterus randalli</i>     | Threadfin bream (red)    | 10 TL                |
| 7.    | <i>Saurida undosquamis</i>     | Lizardfish               | 10 TL                |
| 8.    | <i>Pampus argenteus</i>        | Silver pomfret           | 13 TL                |
| 9.    | <i>Parastromateus niger</i>    | Black pomfret            | 17 TL                |
| 10.   | <i>Priacanthus hamrur</i>      | Bulls eye                | 14 TL                |
| 11.   | <i>Otolithes ruber</i>         | Tiger toothed croaker    | 17 TL                |
| 12.   | <i>Epinephelus diacanthus</i>  | Spiny cheek grouper      | 18 TL                |
| 13.   | <i>Gymnura poecilura</i>       | Butterfly ray            | 29 DW                |

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## Introduction

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide ie, CCS (carbon capture and storage). This is one of the methods of reducing the levels of carbon di oxide (CO<sub>2</sub>) in the atmosphere with the goal of reducing climate change impacts globally. The Paris Conference on Climate Change has set certain targets to reduce greenhouse gasses (GHGs) from atmosphere. To achieve these targets, GHGs should actively be removed from atmosphere and stored safely. The capture and storage of carbon will be key to reducing the future emissions of GHGs. Carbon sequestration is being carried out by many ways. Sequestration of carbon by any living forms especially plants is regarded as bio sequestration of carbon. Storing carbon in underground geological formations is regarded as geo sequestration and deep in ocean means ocean sequestration, whose consequence is not known and cost intensive.

## Carbon in atmosphere and cause of its rise

It is well known that the global average concentration of atmospheric CO<sub>2</sub> rose to 387 parts per million (ppm) in December 2009 (ESRL/NOAA 2009) to 409 ppm on 16 Sept 2018 (NASA, Global Climate Change, 2018) the highest level it has reached over the past 800 000 years (Lüthi et al. 2008) and more than 38% above the pre-industrial value of roughly 280 ppm (Raupach and Canadell 2008). It is generally agreed that the anthropogenic greenhouse gas emission in the globe during the year 2000 – 2010 were the highest in history (IPCC, 2014). CO<sub>2</sub> absorbs and emits infrared radiation at wavelengths of 4.26 µm and 14.99 µm and hence known as GHG which has a vital role to play in regulating the Earth's surface temperature. CO<sub>2</sub> is one of the heat-trapping GHGs which is



released through human activities like deforestation and burning fossil fuels (Solomon et al. 2007). Increasing levels of dissolved CO<sub>2</sub> cause significant drop in pH of seawater which in turn adversely affects the marine life and coastal ecosystem.

### **Why is carbon sequestration needed?**

Another reason carbon dioxide is important in the earth system is that it dissolves into the ocean like the fizz in a can of soda. It reacts with water molecules, producing carbonic acid and lowering the ocean's pH. Since the start of the Industrial Revolution, the pH of the ocean's surface waters has dropped from 8.21 to 8.10. This drop in pH is called ocean acidification. A drop of 0.1 may not seem like a lot, but the pH scale is logarithmic; a 1-unit drop in pH means a tenfold increase in acidity. A change of 0.1 means a roughly 30% increase in acidity. Increasing acidity interferes with the ability of marine life to extract calcium from the water to build their shells and skeletons. Number of studies suggest that the current trend of pH reduction and increasing levels of dissolved CO<sub>2</sub> will have negative impacts on number of marine organisms;

- Calcification impairment in corals (Jokiel, 2008; Marubini et al., 2008).
- Morphological and compositional changes in the skeletons of the newly recruited corals (Cohen et al., 2009).
- Promotes shell dissolution in marine paper shell, *Nucella lamellose* (Nienhuis et al., 2010).
- Recruitment failure in the threatened Caribbean coral, *Acropora palmata* (Albright et al., 2010).
- Dissolution of marine bivalve shells and spines of seaurchin (Kaladharan et al., Communicated).

### **Blue carbon sinks**

The carbon (C) sequestered in vegetated coastal ecosystems, especially mangrove forests, seagrass meadows and salt marshes, has been termed *Blue Carbon* and these coastal habitats are known as Carbon sinks. Although their global area is one to two orders of magnitude lesser than that of terrestrial habitats, the contribution of vegetated coastal ecosystems per unit area to long-term C sequestration is much greater, in part because of their efficiency in trapping suspended matter and associated organic C during tidal inundation. It is a point of serious concern that these carbon sinks are being lost at faster rates. Marine primary producers such as planktonic algae and seaweeds are known to



relegate excess CO<sub>2</sub> from seawater (Kaladharan *et al.*, 2009) although they are not considered as true carbon sequesters as the carbon fixed is recycled soon upon decay. Marine macrophyte communities tend to produce excess organic matter that can be stored in sediments or exported to adjacent ecosystems. Seaweeds and seagrasses store about 0.4 and 16% of their net primary production in the sediments, respectively (Duarte and Cebrián, 1996), and some of the excess organic matter they produce can be exported to adjacent waters. The export of organic matter has been reported to account, on average, for 25 and 44% of the net primary production of macroalgae and seagrass, respectively. Dissolved organic carbon (DOC) release from macroalgae represented from 1 to 39% of gross primary production compared to only <5% from seagrasses (Khailov and Burlakova, 1969; Brilinsky, 1977; Pregnall, 1983).

### **Experiment to demonstrate carbon sequestration by seaweeds**

To demonstrate the carbon sequestration potential of seaweeds, following experiment has been designed.

- Live samples of seaweeds, two species each from three groups of seaweeds to be collected.
- Wash thoroughly with excess seawater to remove sand, debris and attached phytoplankton and fauna if any and bring to the laboratory.
- Acclimatize them for three days in a 500 l tank with running seawater (32 PSU) and 12 hour photoperiod.
- Weigh 5g of each seaweed species in separate glass bottles (1 lit) with suitable replicates and label the bottles accordingly.
- Filter the seawater of 32 PSU to remove phytoplankton through 0.45µ filter paper.
- Fill carbonated seawater (0, 50, 100, 150 and 200 ppm, using a soda maker) and keep them airtight with lids.
- Check the pH and dissolved CO<sub>2</sub> (Dye, 1958, shown below) levels in each bottle and record the values in data register.
- Introduce each species of seaweeds weighed already in one set of bottles separately and mark them as Experimental and those without seaweeds as Control.
- Incubate them under sunlight for two hours through a running water filter to avoid rise in temperature.
- After two hours quickly check the pH and CO<sub>2</sub> levels in each bottle and record the changes if any.

### **Estimation of dissolved Carbon dioxide (Dye, 1958)**

#### **Reagents:**

- Phenolphthalein indicator

- Standard Sodium hydroxide solution (0.022N): Dilute 22.7 ml of 1 N NaOH (40 g/L) to one L CO<sub>2</sub> free distilled water in a volumetric flask. One ml is equivalent to 1.0 mg of CO<sub>2</sub>. Prepare just before estimation.

OR

- Standard Sodium carbonate solution (0.045N): Dissolve 2.407 g anhydrous sodium carbonate in one L CO<sub>2</sub> free distilled water in a volumetric flask. One ml is equivalent to 1.0 mg of CO<sub>2</sub>. Prepare just before estimation.

***Procedure:***

Collect water samples in a glass stoppered pyrex bottle and completely fill the bottle without leaving any air space.

Add 5-10 drops of Phenolphthalein indicator and shake well. (In the absence of dissolved CO<sub>2</sub> a pink colour appears and absence of pink colour formation indicates the presence of dissolved CO<sub>2</sub>).

Carefully siphon out 100 ml of the sample into 250 ml conical flask and then titrate with standard Na<sub>2</sub>CO<sub>3</sub>/ NaOH solution.

Stir gently using a plunger stirrer until the pink color persists for 30 sec.

***Calculation:***

$$\text{Quantity of dissolved CO}_2 \text{ (mg/l)} = \frac{\text{ml alkali used} \times 1000}{\text{Vol. of sample used}}$$

If one is interested to see the primary productivity of seaweed samples in the presence of CO<sub>2</sub>, siphon out water from each bottles carefully without entangling any air bubbles into 125ml BOD bottles for determining oxygen produced for determining the productivity (GPP and NPP) were measured using Winkler's method. In that case one should measure the dissolved oxygen before the incubation in light.

The difference between the levels of CO<sub>2</sub> before the start of incubation and after the incubation period formed the carbon sequestration potential of different species of seaweeds.

Seagrasses and seaweeds grow more rapidly under elevated CO<sub>2</sub> levels (Zimmerman et al., 1997; Unsworth et al., 2012; Manzello et al., 2012). Seaweed beds along the coastal region act as net sink of atmospheric CO<sub>2</sub>. Seaweed

communities are strongly autotrophic, generating far more organic matter through photosynthesis than consumed by respiration in the ecosystem, and are thus responsible for much of CO<sub>2</sub> capture in marine vegetated habitats (Duarte and Cebrian, 1996). Seaweed mariculture has been recognized as one of the climate resilient aquaculture techniques to mitigate ocean acidification (Kaladharan, 2013; Zacharia et al., 2015; Duarte et al., 2017). An upper limit to the CO<sub>2</sub> capture potential of seaweed aquaculture can be calculated at 2.48 million tons of CO<sub>2</sub> (0.68 Tg C) per year. This upper limit assumes that all of the 27.3 million tons fresh weight produced in 2014 be dedicated to carbon capture with a 100% yield given by the average carbon content of 24.8% of seaweed dry weight (Duarte, 1992). From this it is presumed that one ton wet weight of seaweed can sequester 0.0984 ton of CO<sub>2</sub> per year. Hence large scale seaweed mariculture along the coastal area is the only green and cost effective method of carbon sequestration while the harvested biomass can support alternative livelihood to the coastal fishers.

Table: Change in CO<sub>2</sub> and pH in carbonated seawater with or without live seaweed samples

(Species: ..... )

| Bottle id | CO <sub>2</sub> (ppm) spiked | Initial CO <sub>2</sub> (ppm) | Initial pH | Wt of seaweed (gm) | CO <sub>2</sub> After 2 hours | pH after 2 hours | Δ pH | Δ CO <sub>2</sub> |
|-----------|------------------------------|-------------------------------|------------|--------------------|-------------------------------|------------------|------|-------------------|
| 1         | 0*                           |                               |            | 0                  |                               |                  |      |                   |
| 2         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 3         | 50                           |                               |            | 0                  |                               |                  |      |                   |
| 4         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 5         | 100                          |                               |            | 0                  |                               |                  |      |                   |
| 6         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 7         | 150                          |                               |            | 0                  |                               |                  |      |                   |
| 8         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 9         | 200                          |                               |            | 0                  |                               |                  |      |                   |
| 10        |                              |                               |            | 5.0                |                               |                  |      |                   |
| 11        | 250                          |                               |            | 0                  |                               |                  |      |                   |
| 12        |                              |                               |            | 5.0                |                               |                  |      |                   |
| 13        | 300                          |                               |            | 0                  |                               |                  |      |                   |
| 14        |                              |                               |            | 5.0                |                               |                  |      |                   |

\* Triplicates for each concentration of CO<sub>2</sub> used

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## Introduction

The global climate has changed since the preindustrial period. A number of evidences are now available that these changes have a few positive and many negative impacts on organisms and ecosystems, as well as human systems and wellbeing. The global mean surface temperature (GMST), which increased by 0.87°C in 2006-2015 relative to preindustrial period of 1850-1900, will increase further to 1.5°C or higher by 2030-2040 with increased magnitude of impacts on natural and human systems (IPCC, 2014). Until recently, information on evidence-based impacts of climate change were available for a global warming of 0.87°C or less. After the release of Special Report of the Intergovernmental Panel on Climate Change (IPCC) in October 2018, direct information and predictions on the impacts of global warming of 1.5°C and up to 2°C are now available.

In its Fifth Assessment Report (AR5), the IPCC (2014) evaluated the changes to natural systems, and the impact on human communities and industry. While impacts varied substantially between systems, sectors and regions, many changes over the past 50 years were attributed to human-driven climate change and its impacts. Risks were observed to be increasing for natural ecosystems as climate extremes increase in frequency and intensity. In association with the changes with the natural ecosystems, the associated fauna and flora will be shifting their biogeographical ranges to higher latitudes and altitudes. This will have consequences for ecosystem services and human dependence. AR5 also reported increasing evidence of changing patterns of disease, invasive species as well as growing risks for coastal communities and industry, especially in the context of sea level rise and human vulnerability.

For assessing possible impacts on natural and managed systems at 1.5°C and above, the IPCC (2018) used the following approaches: (i) Identifying impacts of global 0.5°C warming in the observational record of previous decades, assuming that the impacts would scale linearly for higher levels of warming; (ii) Using conclusions from past climates combined with modeling of the relationships between climate drivers and natural systems; and (iii) More complex approach on laboratory or field experiments which provide useful information on the causal effect of a few factors (which can be as diverse as climate, greenhouse gases (GHG), management practices, biological and ecological factors) on specific natural systems. The major conclusions arrived by IPCC (2018) for marine ecosystems are given here.

### **Oceans systems**

The Ocean plays a central role in regulating atmospheric gas concentrations, global temperature and climate. It also provides habitat to a large number of organisms and ecosystems that provide goods and services that are worth trillions of USD per year (e.g., Costanza et al., 2017). Together with local stresses, climate change poses a major threat to an increasing number of ocean ecosystems (e.g. coral reefs) and consequently for many coastal communities who depend on marine resources for food, livelihoods and a safe place to live. Changes in the ocean include rapid increases in ocean temperature down to at least 700 m depth. It is *virtually certain* that the surface temperature of the upper layers of the ocean (0–700 m) have warmed over the period 1950–2016 by 0.11°C, 0.07°C, and 0.05°C per decade for the Indian, Atlantic and Pacific oceans, respectively with the greatest changes occurring at high latitudes. There is also evidence of significant increases in the frequency of marine heatwaves, consistent with changes in mean ocean temperatures. Increasing climate extremes in the ocean are associated with the general rise in global average surface temperature as well as more intense patterns of climate variability (e.g., climate change intensification of ENSO). Increased heat in the upper layers of the ocean is also driving more intense storms and greater rates of inundation, which, together with sea level rise, are already driving significant impacts to sensitive coastal and low-lying areas.

Ocean chemistry is also changing with the global temperature increase of 1.5°C. Projected changes in the upper layers of the ocean include pH, oxygen content, as well as sea level. Seawater is slightly basic (meaning pH > 7), and ocean acidification involves a shift towards pH-neutral conditions rather than a transition to acidic conditions (pH < 7). Anthropogenic carbon dioxide has

decreased the pH, as well as affected the concentration of ions (such as carbonate) in seawater. About 30% of CO<sub>2</sub> emitted by human activities, for example, has been absorbed by the ocean where it has combined with water to produce a dilute acid that leads to ocean acidification. Ocean pH has decreased by 0.1 pH unit since the Pre-Industrial Period, which is unprecedented in the last 65 to 300 million years. Experimental manipulation of CO<sub>2</sub>, temperature and consequently acidification indicate that these impacts will continue to increase in size and scale as CO<sub>2</sub> and SST continue to increase in tandem. As CO<sub>2</sub> concentrations continue to increase along with other GHGs and SST increase of 1.72°C, the pH will decrease linearly to 0.22 pH unit (relative to the preindustrial period). These changes are likely to continue given the linear correlation of SST and pH.

Increasing surface water temperatures have reduced the oxygen concentration in the ocean by 2% since 1960. Changes to ocean mixing and metabolic rates (due to increased temperature and supply of organic carbon to deep areas) have increased the frequency of 'dead zones', areas where oxygen levels no longer support oxygenic life.

Ocean salinity is changing in directions that are consistent with surface temperatures and the global water cycle (i.e. evaporation and inundation). Some regions (e.g. northern oceans and Arctic regions) have decreased salinity (i.e. due to melting glaciers and ice sheets) while others are increasing in salinity due to higher sea surface temperatures and evaporation. These changes in salinity (density) are also potentially driving changes to large scale patterns of water movement.

Increased ocean temperature has intensified the storms. Storms, wind, waves and inundation can have highly destructive impacts on ocean and coastal ecosystems as well as the human communities that depend on them. The intensity of tropical cyclones across the world's ocean has increased although the overall number of tropical cyclones has decreased. The direct force of wind and waves associated with larger storms, along with changes in storm direction, increase the risks of physical damage to coastal communities as well as ecosystems such as mangroves and tropical coral reefs. These changes are associated with increases in maximum wind speed, wave height and inundation, although the trends vary from region to region. In some cases, this can lead to increased exposure to related impacts like reduced water quality and sediment run-off. More intense storms have the potential (along with other factors such as



disease, food web changes, invasive organisms and heat stress mortality) to offset the capacity for natural and human systems to recover from disturbances. Observations on precipitation show that there are more areas with increases than decreases in the frequency, intensity and/or amount of heavy precipitation.

Importantly, changes in the response to climate change act synergistically and rarely operate in isolation (Fig. 1). Hence, the effect of global warming at 1.5°C must be considered in the light of multiple, interactive factors that may produce complex risks and impacts on human and natural systems.

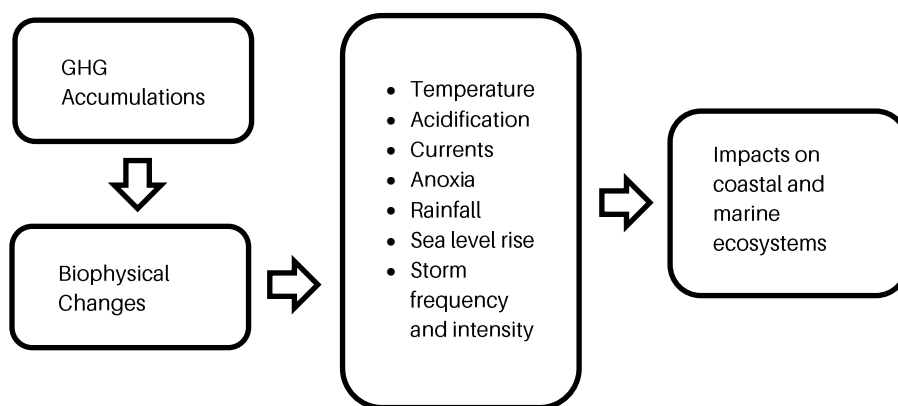


Figure 1. The pathway by which climate change impacts coastal and marine ecosystems

### **Impact on marine ecosystems**

The developmental rates of poikilotherms, where body temperatures vary with the environment, increase exponentially with temperature, with important consequences including larval dispersal, population connectivity, local adaptation, and speciation. Marine organisms are already responding to climate change by shifting their biogeographical ranges to higher, cooler latitudes, at rates that range from 0 to 40 km per year. This has affected the structure and function of the ocean, along with its biodiversity and food webs. Movements of organisms do not necessarily result in movement of entire ecosystems. For example, the oil sardine has been observed to expand its geographic ranges to the northern latitudes along the Indian coast, but this has not resulted in the expansion of entire coastal ecosystems from the southern latitude to the northern latitude. In the case of 'less mobile' ecosystems (e.g. coral reefs, kelp forests, intertidal communities), shifts in biogeographical ranges may be limited with mass mortalities and disease outbreaks increasing in frequency as the

exposure to extreme temperatures increases. These trends will become more pronounced at 1.5°C, and even more at 2°C and are likely to result in decrease in marine biodiversity at the equator and increase in biodiversity at higher latitudes.

While the impacts of relocating species are mostly negative for human communities and industry, there are instances of short-term gains. Fisheries, for example, may expand temporarily to the northern latitudes. One example, as mentioned in the previous paragraph, is the latitudinal expansion of oil sardine from southern latitudes to northern latitudes along the east and west coasts of India (Vivekanandan, 2011). Fisheries in temperate waters and in high latitudes are influenced by the temperature on Net Primary Productivity (NPP) as well as on fish and fisheries. Low and mid latitudes, on the other hand, increase in sea temperature is driving decrease in NPP due to the direct effects of elevated temperatures and/or reduced ocean mixing from reduced ocean upwelling (increased stratification). Reduced ocean upwelling has implications for millions of people and industries that depend on fisheries for food and livelihoods.

Changes in ocean circulation also can have profound impacts on marine ecosystems. Ocean circulation connects regions and facilitates the entry and establishment of species in areas where they were unknown before (e.g., 'tropicalization' of temperate ecosystems) as well as the arrival of novel disease agents. For example, the sea urchin, *Centrostephanus rodgersii*, a herbivore, has been able to reach Tasmania, where it was previously unknown, from the Australian mainland due to strengthening of East Australian Current. As a consequence, the distribution and abundance of kelp forests has rapidly decreased with implications for fisheries and other ecosystem services.

Numerous risks have been identified associated with ocean acidification. Changes in pH of seawater are having, and are likely to have, fundamental and substantial impacts on a wide variety of organisms. Organisms with shells and skeletons made out of calcium carbonate are particularly at risk, as are the early life history stages of a broad number of organisms and processes such as decalcification. Some taxa do not show the same sensitivity to changes in CO<sub>2</sub>, pH and carbonate concentrations. Moreover, these risks vary with latitude (maximum changes at high latitudes) and depths. While many risks have been identified through laboratory and mesocosm experiments as the result of acidification, there is a growing list of impacts from the field that includes community scale impacts on bacterial assemblages and processes, coccolithophores, pteropods and polar food webs, phytoplankton, benthic

ecosystems, seagrass, macroalgae, as well as sponges, endolithic microalgae, and reef-building corals.

As the number of 'dead zones' (areas where oxygenic waters have been replaced by hypoxic conditions) has been growing strongly since the 1990s, some impacts related to deoxygenation include expansion of Oxygen Minimum Zones (OMZ), physiological impacts, and mortality and/or displacement of oxygenic organisms such as fish and invertebrates. Deoxygenation interacts with ocean acidification to present substantial and combined challenges for fisheries and aquaculture. The number of hypoxic areas continues to increase and is likely to have greater impacts as ocean warming and acidification increases.

Sea level increases are interacting with other factors such as strengthening storms, which together are driving greater storm surge, infrastructure damage, erosion and habitat loss. Coastal wetland ecosystems such as mangroves, seagrasses and salt marshes are under pressure from rising sea level as well as a wide range of other non-climate change related risks and impacts. The loss of wetlands due to sea level rise has been recently estimated at approximately 1% per annum across a large number of countries. While some ecosystems (e.g. mangroves) may be able to shift shoreward as sea levels increase, coastal development (e.g. coastal building, seawalls, and agriculture) can often interrupt shoreward shifts of mangroves. The response to sea level rise include reducing the impact of other stresses such as those arising from tourism, fishing, coastal development and reduced sediment supply. In some cases, restoration of coastal habitats and ecosystems may be a cost-effective way of responding to changes arising from increasing levels of exposure from rising sea levels, intensifying storms, coastal inundation, and salinization.

### **Framework organisms (tropical corals, mangroves and seagrass)**

Marine framework organisms ('ecosystem engineers'), such as seagrass, kelp, oysters, salt marsh species, mangrove and corals build physical structures or frameworks (i.e. seagrass meadows, kelp forests, oyster reefs, salt marshes, mangrove forests and coral reefs) which form the habitat for large numbers of species. These organisms in turn provide food, livelihoods, cultural significance, and services such as coastal protection.

Coral dominated reefs are found between latitude 30°S and 30°N along coastlines where they provide habitat for over a million species. The food, income, coastal protection, cultural context, and many other services for millions

of people along tropical coastal areas are provided by corals. More recently, climate change has emerged as the greatest threat to coral reefs. With temperatures of just 1°C above the long-term summer maximum remaining for 4-6 weeks, the corals undergo mass coral and mortality. Tropical coral reefs face very high risks of becoming unsustainable if warming exceeds 1.5°C. Even with warming until today (0.87°C), a substantial proportion of coral reefs have experienced large scale mortalities (Vivekanandan et al., 2009). In the last 3 years alone, large coral reef systems such as the Great Barrier Reef (Australia) have lost as much as 50% of their shallow water corals.

On a global scale, the distribution and abundance of coral reefs has decreased by approximately 50% over the past 30 years as a result of pollution, storms, overfishing and unsustainable coastal development. Ocean warming and acidification can also slow growth and calcification, making corals less competitive to other benthic organisms such as macroalgae. As corals disappear, so do fish stocks, and many other reef-dependent species, directly impacting industries such as tourism and fisheries, as well as coastal livelihoods for many. These impacts are exacerbated by increasing intensity of storms, which physically destroy coral reefs, and by ocean acidification which can weaken coral skeletons, contribute to disease, and slow the recovery of coral communities.

Predictions of bleaching events and decline of coral abundance is possible now. Recent models are capable of predicting large-scale loss of coral reefs. These predictions indicate large-scale loss of corals by mid-century under even low emission scenarios. Even if emission reduction is achieved and the temperature increase is restricted to 1.5°C, there will be further loss of 90% of reef-building corals compared to today. If the temperature increases to 2°C or more above the pre-industrial period, 99% of corals will be lost.

Tropical coral reefs are found down to depth of 150 m and are dependent on light, as distinct from the cold deep-water reef systems that extend down to depths of 2000 m or more. Due to difficulty in accessing deep-water reef systems, the literature on impacts of climate change is limited compared to that of tropical coral reefs.

Risks of climate change impacts for seagrass and mangrove ecosystems have recently been assessed by an expert group led by Short et al. (2016). Impacts of climate change were similar across a range of submerged and emerged plants.

Submerged plants such as seagrass were affected mostly by temperature extremes and indirectly by turbidity, while emergent communities such as mangroves and salt marshes were most susceptible to sea level variability and temperature extremes. If the global warming reaches 1.8°C above the preindustrial period, seagrasses are projected to reach moderate to high levels of risk due to sea level rise, erosion, damage from extreme temperatures and storm damage. Projection of the future distribution of seagrasses suggest that tropical, low latitude seagrass communities will reduce due to increasing stress levels and there will be a poleward shift. For mangroves, recent assessments suggest that climate change risks are moderate, i.e., moderate risks start at 1.3°C due to sea level rise and more frequent heat stress mortality.

Strategies for reducing the impact of climate change on framework organisms include reducing non-climate change stresses (e.g. coastal pollution, overfishing, destructive coastal development) in order to increase ecological resilience in the face of accelerating climate change impacts. A full understanding of the utility and feasibility of the role of refugia in reducing the loss of ecosystems has yet to be developed. There is also interest in *ex situ* conservation approaches involving restoration of corals via aquaculture and 'assisted evolution' to help corals adapt to changing sea temperatures. However, there are numerous challenges for these approaches, which have to be cost effective.

Integrating coastal infrastructure with ecosystems dependent on mangroves, seagrasses and salt marsh is necessary such that they are able to shift shoreward as sea levels rise. Maintaining sediment supply to coastal areas will enable mangroves keep pace with sea level rise. In addition, integrated coastal zone management should recognize the importance of using natural ecosystems such as mangroves and tropical coral reefs to protect coastal human communities. High levels of adaptation will be required to prevent impacts on food security and livelihoods in general. Adaptation options include developing alternative livelihoods and food sources, ecosystem-based management/adaptation such as ecosystem restoration, and constructing coastal infrastructure that reduces the impacts of rising seas and intensifying storms. Clearly, these options need to be carefully assessed in terms of feasibility, cost and scalability, as well as in the light of the coastal ecosystems involved.

## **Ocean food webs**

Ocean food webs are interconnected systems that transfer solar energy and nutrients from phytoplankton to higher trophic levels (including apex predators) as well as through other food web interactions. Animal metabolism is temperature-dependent, and consequently ecological processes such as predator-prey interactions are likely to be altered as warming occurs. Global warming and ocean acidification are forecast to exert significant impacts on marine food webs. Using a sophisticated mesocosm experiment, Ullah et al (2018) modelled energy flows through a species-rich multilevel food web, with live habitats, natural abiotic variability, and the potential for intra- and intergenerational adaptation. They have shown experimentally that the combined stress of acidification and warming reduced energy flows from the first trophic level (primary producers and detritus) to the second (herbivores), and from the second to the third trophic level (carnivores). Warming in isolation also reduced the energy flow from herbivores to carnivores, the efficiency of energy transfer from primary producers and detritus to herbivores and detritivores, and the living biomass of detritivores, herbivores, and carnivores. Whilst warming and acidification jointly increased primary producer biomass through an expansion of cyanobacteria, this biomass was converted to detritus rather than to biomass at higher trophic levels, i.e., production was constrained to the base of the food web. The results show how future climate change can potentially weaken marine food webs through reduced energy flow to higher trophic levels and a shift towards a more detritus-based system, leading to food web simplification and altered producer-consumer dynamics, both of which have important implications for the structuring of benthic communities. However, greater focus on incorporating predation and competition interactions into models will significantly improve the ability to identify species and industries most at risk from climate change.

As with many risks associated with impacts at the ecosystem scale, most adaptation options focus on the management of non-climate change stresses from human activities. Reducing non-climate change stresses such as pollution and habitat destruction will be important in efforts to maintain these important food web components. Fisheries management at local to regional scales will be important in reducing stress on food web organisms, as well as helping communities and industries adapt to changing food web structure and resources. One strategy is to maintain higher population levels of fished species in order to provide more resilient stocks in the face of challenges driven by climate change.

Table 1. Summary of projected risks to marine ecosystems at 1.5°C above pre-industrial level (IPCC, 2018)

| Driver                               | Risk   | Risk level  | Regions of high risk        | Adaptation potential |
|--------------------------------------|--|-------------|-----------------------------|----------------------|
| Warming & Stratification             | Loss of corals                                 | High        | Tropical/Subtropical        | High                 |
|                                      | Loss of seagrass                               | Medium      | Tropical/Subtropical        | Medium               |
|                                      | Loss of mangroves                              | Medium      | Tropical/Subtropical        | Medium               |
|                                      | Disruption of food webs                        | Low         | Global                      | Medium               |
|                                      | Migration                                      | Medium      | Global                      | Medium               |
|                                      | Loss of fisheries                              | Medium/High | Global                      | Medium               |
| Acidification & Elevated temperature | Loss of coastal ecosystems                     | Low/Medium  | Tropical/Subtropical        | Medium               |
|                                      | Loss of bivalves                               | Medium      | Temperate upwelling regions | Medium/High          |
|                                      | Changes to physiology of species               | Low/Medium  | Global                      | Low                  |
| Deoxygenation                        | Increased hypoxic zones                        | Low         | Global                      | Low                  |
|                                      | Change in upwelling productivity               | Low         | Most upwelling regions      | Low                  |
| Intensified storm                    | Loss of coastal ecosystems                     | High        | Tropical/Subtropical        | Medium               |
|                                      | Destruction of properties & loss of livelihood | High        | Global                      | Medium               |
| Sea level rise                       | Areas exposed                                  | High        | Asia                        | Medium               |
|                                      | Population exposed                             | High        | Asia                        | Medium               |

## Conclusion

Refugia or Marine Protected Areas may play an important role in terms of conservation of marine ecosystems, especially if they are protected from non-climate change risks. Given the marine ecosystems to heat stress, even short periods of temperature increase will be very challenging. Reduction in the services provided by marine ecosystems will increase poverty levels, highlighting the key issue of equity for the millions of people that depend on these valuable ecosystems. Addressing these challenges related to coastal and

marine ecosystems is increasingly becoming important. Given the scale and cost of these interventions, implementing them earlier rather than later is necessary.

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### Introduction

Climate change, as we know today, refers to collective changes in the characteristic regional climate conditions arising as an aftermath of increased carbon dioxide (CO<sub>2</sub>) emission into the atmosphere by a conglomerate of anthropogenic activities. Climate change is predicted to affect individual organisms during all life stages, thereby affecting populations of a species, communities and the functioning of ecosystems. The effects of climate change in aquatic ecosystems can be direct, through changing water temperatures and associated phenology, the lengths and frequency of hypoxia events, through ongoing ocean acidification trends or through shifts in hydrodynamics and in sea level. The vulnerability of a species to climate change is generally considered as the extent to which abundance or productivity of species in a region could be impacted by climate change and decadal variability.

Alterations in the fishery and fishery resource profile in turn affect the coastal fishing communities dependent on fishing for their livelihood. In addition to this, extreme climatic events often take a heavy toll on fishing and allied activities. Some of the common and direct impacts of climate change on marine fisheries and marine fishing communities include:

- Changes in ocean currents and water column mixing, which alter larval dispersal and food availability. Typically, warm water increases stratification, decreasing productivity.
- Changes in primary productivity, which influence distributional shifts and abundance of several fish species leading to redistribution of stocks and species, and consequent changes in species composition in the fishery as well as altered trophic level interactions.
- Introduction or survival of invasive species.

- Emergence of harmful algal blooms and spread of bacterial/viral diseases.
- Changes in timing of ecological events, which could alter the biological performance of key species leading to alterations in fishery recruitment patterns.
- Elevated sea levels which may kill coral reefs and other living communities that constitute habitat for fish and shellfish, particularly in estuaries, and coastal erosion, which may lead to loss of berthing facilities and fishing hamlets established close to the sea.

### **Positive impacts of Climate change**

Climate change can, and in some cases already does, affect fisheries in many ways; some effects have been clearly documented, and others are only a matter of speculation. Many effects are uncertain and most have not yet been quantified. While people tend to view any change from the current status as negative, some changes may have positive effects, such as faster growth of fish and shellfish, and extension of range into newly productive regions. Predicted fisheries effects of climate change fall into two classes: those associated with the biological health and viability of fish stocks, and those that impinge on the safety or the social, cultural, and financial sustainability of fishermen and fishing communities.

### **Assessing the vulnerability of fish species to climate change**

There is ample evidence of the impacts of global climate change on marine environments. Organisms, however, do not respond to approximated global averages. Regional changes are more relevant in the context of ecological response to climate change. Hence, global-scale climate models may be unable to simulate observed changes in temperature and rainfall or the intensification of coastal upwelling in many areas, but regional-scale models may be able to do this. The prioritization of resources to inform adaptation of commercial fisheries could consider the economic value of fisheries, importance of species to ecosystem function, potential of species to respond favourably to adaptation interventions and/or the probability of persisting through significant environmental change. Against the background of changing climate, which we know is a definite happening event, and the paucity of accurate information on the actual changes that this event induces or can induce in different fish species, there is a large uncertainty hovering over Indian marine fisheries, which already faces the threat of overfishing and pollution impacts. Vital information for fishery managers and policy-makers therefore, would ideally be an exhaustive information base on the likely effects of changing climate on major fishery-

supporting species of finfishes and shellfishes. Overall impact of climate change on fishery and ecological interactions is given in flow chart (Fig 1)

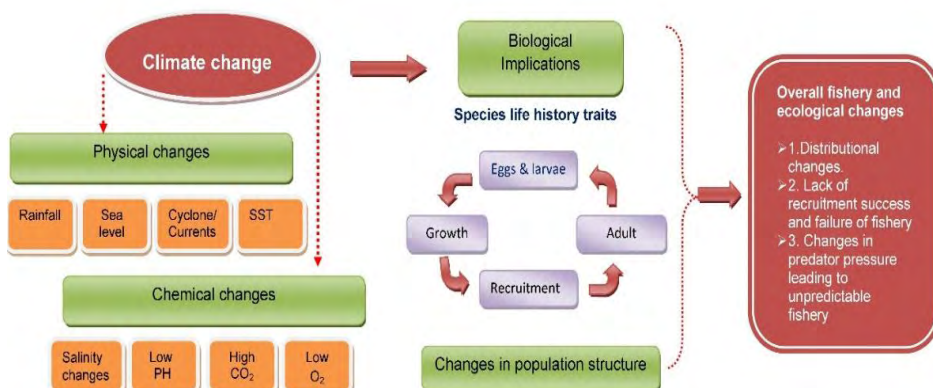


Figure 1. Flowchart of the impact of climate change on fisheries

Vulnerability assessments provide framework for evaluating climate impacts on different species with the aid of existing information and combining the exposure and the sensitivity of a species to a stressor. Vulnerability assessments (VAs) can be used for many different purposes, including improving adaptation planning (designing of policies and interventions), raising awareness of risks and opportunities, and advancing scientific research.

Methods for assessing species vulnerability have been described through quantitative approaches developed to examine climate impacts on productivity, abundance and distribution of different species of marine fishes and invertebrates Fisheries offers several socio-economic benefits to coastal fishing communities, and early warning of potential changes to fish stocks will provide managers and other stakeholders the opportunity to adapt to these impacts. Vulnerability of Indian fish stocks was conducted on identified priority species that contribute significantly to the fishery along the Indian coast, and on which substantial biological information were already available. The outcome of the study is envisaged to provide a strong base for evolving strategic fishery management plans for highly vulnerable stocks to counter the likely impacts of a changing climate in the long run.

## Methodology

Assessment of the vulnerability of individual fish and invertebrate species to climate change is a prerequisite to understand or predict changes in the species

composition and abundance in a particular region. While it is an established fact that climate change influences the marine environment, distribution and abundance of marine species and their phenology in spatial and temporal scales, the impact of climate change on marine organisms may not be uniform for all species and regions as it depends on the biological and behavioural characteristics of the organisms.

Investigations on the impact of climate change on many economically important marine species have been carried out in different parts of the world. A transparent assessment methodology was developed by Morrison et al. (2015) to determine the relative vulnerability of fish stocks to changing climate. The assessment takes into account the impacts of climate change induced by anthropogenic influences and natural factors. Most vulnerability assessment methods are based on two components – exposure and sensitivity of the species to different criteria, which include environmental parameters (exposure attributes), species biological characteristics and anthropogenic influence on the species (sensitivity attributes) and some studies incorporate a third component, adaptive capacity defined by biological characteristics that aid the species to overcome the negative impacts of high sensitivity or exposure. Some studies combine adaptive capacity with sensitivity.

The criteria developed in these studies were suitable for temperate and semi-tropical countries where species diversity is less, and there are relatively few methods of fishing operations. For a tropical country like India with wide variations in environmental parameters and a marine fishery which is characteristically multi-species, multi-gear and multi-ground, these criteria are insufficient to present a true picture of species vulnerability. Therefore in line with the methodologies described in earlier studies, sets of environmental, biological and fishery-based criteria were developed to suitably define the characteristics of tropical Indian species of fishes and invertebrates and their fishery in the region (Table 1).

Table 1. Criteria developed for vulnerability assessment

| Environmental criteria           | Biological criteria             | Fishery related criteria |
|----------------------------------|---------------------------------|--------------------------|
| Sea surface Temperature          | Fecundity                       | Anomaly in CPUE          |
| Rainfall                         | Complexity in early development | Exploitation rate        |
| Ocean current Speed              | Growth coefficient              | Price                    |
| Ocean current direction (S to N) | Trophic level                   | Gear                     |
| Coastal upwelling index          | Longevity/Life span             |                          |

|                           |                         |
|---------------------------|-------------------------|
| Chlorophyll concentration | Lc/Lm                   |
|                           | Horizontal distribution |
|                           | Duration of spawning    |
|                           | Prey specificity        |

A top-down approach was adopted for developing the criteria for vulnerability assessment (FAO, 2015) with base-line information classified through a series of expert opinion workshops on the subject.

A working group of fifteen scientists working on different groups of finfishes and shellfishes, representing different geographical zones of the Indian coast, with sound knowledge on stock characteristics, fishery biology and ecology, interacted at three national workshops and evolved a suitably modified methodology to be adopted for different species in various zones.

### **Vulnerability Assessment Design**

The primary assumption behind the vulnerability assessment methodology used is that current biological performance indices and expected exposure to climate change can be used to evaluate the relative vulnerability of a species. While exposure (E) is the projected magnitude of change in the physical environment due to climate variations, and defines the nature and degree to which a species is exposed to climatic variations, sensitivity (S) indicates the extent to which a species is affected due to its life history traits influenced, either adversely or beneficially, by anthropogenic activities, and, adaptive capacity (A) defines the ability (or potential) of a species to adjust successfully to climate or environmental change. In this study, we chose to represent the three components as separate sets of attributes. Based on the attributes, each component was assigned a score. The Vulnerability (V) was then estimated from the relation:

$$V = (E+S) - A$$

### **Exposure (E) attributes and their scoring**

Exposure attributes used are those climatic variables which could impact the biological or behavioural characteristics of the selected species. Out of several environmental parameters initially considered for inclusion under exposure attributes, 6 environmental parameters viz., sea surface temperature (SST), rainfall, current speed, current direction, upwelling index and chlorophyll concentration, were selected for as exposure attributes. Table 2 gives the parameters, period and source of data of exposure attributes.

Table 2. Exposure attributes used in the study

| Attribute                          | Period of data          | Data source                    |
|------------------------------------|-------------------------|--------------------------------|
| Sea surface Temperature            | 1975-2014<br>(40 years) | ICOADS                         |
| Rainfall                           | 1975-2014<br>(40 years) | Indian Metrological Department |
| Ocean current Speed                | 1979-2014<br>(36 years) | oceanmotion.org (NASA)         |
| Ocean current direction (S to N) * | 1979-2014<br>(36 years) | oceanmotion.org (NASA)         |
| Coastal upwelling index            | 1975-2014<br>(40 years) | NOAA PFEL                      |
| Chlorophyll concentration          | 1997-2014<br>(14 years) | NASA OceancolorAquamodis       |

Anomalies of sea surface temperature were calculated for a period of 40 years from 1975 to 2014. The sum of the absolute values of extreme negative and positive values of the anomalies were taken. From this value 30, 20 and 10 % were taken to rank the data set of SST as High, Medium and Low, respectively. After scoring, the total number of years with low, medium and high ranks was pooled. The pooled data was then multiplied with 1, 2, and 3 for low, medium and high ranks respectively. The value obtained was summed up and divided by the number of years to obtain the final scores for the respective zones. The value between 0.1-1 was classified as low, 1.1-2 as medium and 2.1-3 as high vulnerability. Similar procedure was followed for rainfall, ocean current speed and direction and chlorophyll concentration. Weightage factors were also accorded to each attribute depending on the exposure of the species to the attribute, limited by its horizontal or vertical spatial distribution (Table 3).

Table 3. Zone-wise and realm-wise weightage given to exposure attributes

| Zone | Realm    | Attribute & weightage |               |                   |           |
|------|----------|-----------------------|---------------|-------------------|-----------|
|      |          | SST                   | Current speed | Current direction | Upwelling |
| NW   | Pelagic  | 1.5                   | 2             | 2                 | 0.75      |
|      | Column   | 1.25                  | 2             | 2                 | 0.75      |
|      | Demersal | 1.0                   | 2             | 2                 | 0.75      |
| SW   | Pelagic  | 1.5                   | 2             | 2                 | 0.5       |
|      | Column   | 1.25                  | 2             | 2                 | 0.5       |
|      | Demersal | 1.0                   | 2             | 2                 | 0.5       |
| SE   | Pelagic  | 1.5                   | 2             | 2                 | 1         |
|      | Column   | 1.25                  | 2             | 2                 | 1         |
|      | Demersal | 1.0                   | 2             | 2                 | 1         |
| NE   | Pelagic  | 1.5                   | 2             | 2                 | 1         |

|          |      |   |   |   |
|----------|------|---|---|---|
| Column   | 1.25 | 2 | 2 | 1 |
| Demersal | 1.0  | 2 | 2 | 1 |

The level of exposure of species to SST varies from surface to the bottom; the species occupying the pelagic realm are more exposed to SST variations than those in the column and demersal realms. For species in the pelagic realm, a weightage of 1.5 was applied for SST while a weightage of 1.25 was given to species distributed in column waters and 1.0 for demersal fishes. In the case of current speed and direction, the weightage was given based on dependency on this parameter for the dispersal of eggs and larvae, with greater weightage of 2.0 given to species with eggs and larvae that are liable to be carried away by current. For upwelling, differential weightage was given for different zones since there is considerable difference in the extent of upwelling along the west and east coasts of India. Upwelling is a seasonal phenomenon along NW and SW coasts of India. However the intensity is more along the SW coast. Accordingly weightage of 0.5 was given to SW coast and 0.75 to north-west coast. Rainfall and chlorophyll was given the same weightage for four zones.

### Sensitivity (S) attributes and their scoring

For sensitivity attributes, the biological characteristics of species that are indicative of their ability or inability to respond to environmental changes and exploitation/fishery related pressures are used. For this study 9 attributes were selected based on time series data for a period 40 years (1975- 2015) on fishery and biology of each species extracted from published information available in CMFRI repository (eprints@cmfri). Data collected through detailed biological study done during 2011-2015 in different zones under the NICRA project was also used.

The sensitivity attributes were scored by the 15 experts working from the Institute on pelagic, demersal, crustacean and molluscan resources. For each attribute, scoring was limited to a scale of 1-3, representing low, medium and high ranking. Table 4 presents the sensitivity attributes and the scale limits for each attribute used in the study.

Table 4. Sensitivity attributes with scale limits for impact scoring

| Attributes                 | Low impact                 | Medium impact            | High impact         |
|----------------------------|----------------------------|--------------------------|---------------------|
|                            | 1                          | 2                        | 3                   |
| <b>Fecundity</b>           | More than 0.5 million eggs | 1000 to 0.5 million eggs | Less than 1000 eggs |
| <b>Complexity in early</b> | Parental care              | Demersal eggs            | Complex lifecycle   |

|   |   |               |                              |
|---|---|---------------|------------------------------|
| <b>development</b>                                    | Pelagic eggs with simple larval development |               | with different larval stages |
| <b>Growth coefficient</b>                             | More than 1                                 | 0.51 to 1     | Less than 0.5                |
| <b>Trophic level</b>                                  | Less than 3                                 | 3-3.9         | More than 4                  |
| <b>Longevity/Life span</b>                            | Less than 2.5 years                         | 2.5 to 5 yrs, | More than 5                  |
| <b>Length of capture (Lc)/ Length at maturity(Lm)</b> | >0.8  | 0.6-0.79      | <0.6                         |
| <b>Anomaly in CPUE*</b>                               | ≥ 1   | ≥ 2           | > 3                          |
| <b>Exploitation rate</b>                              | <0.5  | 0.51-0.7      | >0.7                         |
| <b>Price</b>  | Below Rs 100                                | 100-350       | More than 350                |

### Adaptive Capacity (A) attributes and their scoring

Adaptive capacity attributes used are primarily biological and ecological traits that could help the species to adapt to a fluctuating or changing environment. Four attributes were selected for this study. Based on expert opinion for each attribute the scoring was limited to a scale of 1-3, representing low, medium and high. Table 5 gives the various adaptive capacity attributes used and their scoring.

Table 5. Adaptive capacity attributes with scale limits for adaptability scoring

| <b>Attributes</b>  | <b>Low</b>                        | <b>Medium</b>                          | <b>High</b>                                     |
|--|-----------------------------------|--|---|
|  | <b>1</b>                          | <b>2</b>                               | <b>3</b>  |
| <b>Horizontal distribution</b>                           | Less than 5 states                | 5 to 7 states                          | Distribution in 8 to 9 states (at least 0.5%)   |
| <b>Vertical Distribution</b>                             | 80% catch in depth specific gears | 26-79% catch in 2 depth specific gears | Upto 25% catch from 3 or 4 depth specific gears |
| <b>Duration of spawning</b>                              | Less than 4 months                | Extends from 4 to 7 months             | Spawning extends for 8 months                   |
| <b>Prey specificity/No. of prey groups/Niche breadth</b> | Narrow (<0.3)                     | Medium (0.31-0.69)                     | Broad (>0.7)                                    |

Horizontal distribution was defined from the abundance of the species in commercial fish landings in different zones/states along the Indian coast. Vertical distribution was defined by the maximum occurrence of the species in different gears operated at different depths. Duration of spawning was defined by the number of months with high incidence (50%) of ripe and spawning individuals of the species in the fishery. Prey specificity/Number of prey/niche breadth was defined from research data and from those available in *Fishbase* website.



### Vulnerability (V) assessment

The sum of exposure and sensitivity is the impact. For preparation of vulnerability matrix, climatic variables (exposure attributes) were given more weightage as the sensitivity traits are dependent on changes in the climatic variables. Accordingly the following combinations of exposure and sensitivity scores were fixed as binding -

| S. No. | Exposure | Sensitivity | Impact |
|--------|----------|-------------|--------|
| 1      | L        | M           | L      |
| 2      | M        | H           | M      |
| 3      | H        | M           | H      |
| 4      | L        | H           | M      |

Vulnerability score of <1 was considered as low vulnerability, 1.0-1.5 as medium and >1.5 as highly vulnerable. Vulnerability matrix for different geographical zones was generated by plotting impact versus vulnerability score (Figure. 2).

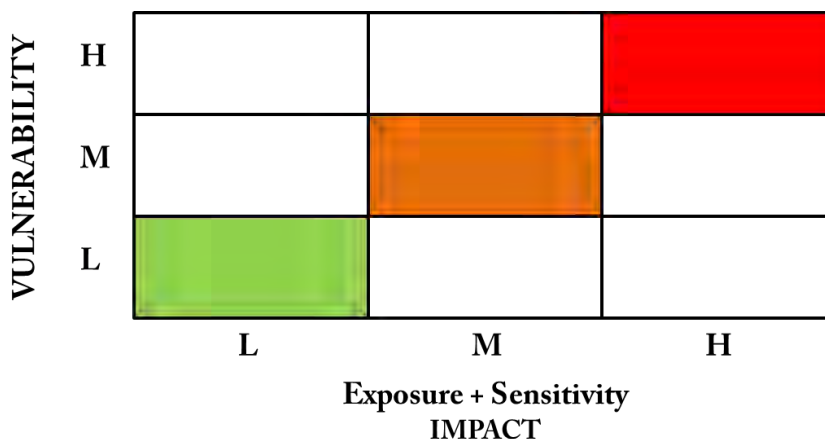


Figure 2. Vulnerability Matrix based on component scores for exposure and sensitivity (impact) and adaptive capacity.

### Using the vulnerability assessment report

Effective management of India's marine fishery is a challenging task, considering its multidimensional diversity facets. Single species assessment and management models are unlikely to create the necessary impacts, and ideally, a concerted approach using a combination of single-species, multispecies and ecosystem based assessments is advocated. Identifying species that are liable to be highly or least impacted by climate change, immediately or in future, will play

a key role in deriving management measures most suited to ensure a sustainable fishery, without impinging on the economic benefits of the fishing communities, particularly the artisanal sector. The ultimate goal of fishery management is to ensure the sustenance of the resource, the fishery and the livelihood of the stakeholders. To this means, such vulnerability assessment reports would serve as the keystone for constructive fishery management options through gear modification and target species diversification so as to decrease targeting of and dependency on highly impacted species and promote fishery of less impacted and resilient species which will help to sustain the fishery in the long run.

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## Introduction

Understanding the impacts of climate change on agriculture, associated landscapes and natural resources is crucial if local development efforts are to be successful. The climate smart village concept is developed based on this where the villages, scientific personnel and local governance join hands to introduce climate smart technologies in the village. The location of a Climate-Smart Village (CSV) is selected based on its climate risk profile and the willingness of farmers/fishermen and local governments to participate in the project.

Researchers conduct a baseline survey to capture the current socio-economic conditions and analyse resource availability, average production and income among other indicators. This enables an impact assessment after a period of time to gauge the benefits of the interventions. Stakeholders convene to prioritize which interventions they will take up, that are best suited to their local conditions. This is done through a choice experiment that analyses their preference and willingness to pay for technologies. Disseminating information on climate-smart fisheries and agriculture practices and outcomes is an important part of the capacity building process. Farmers are encouraged to record their testimonials and feedback at regular intervals and share it with researchers and the community.

Villages are also locations where partners have already established vital links with local communities. After potential sites are selected, a steering group of community representatives and researchers together identify appropriate climate-smart options for that village. These might include climate-smart technologies, climate information services, local development and adaptation

plans and supportive institutions and policies, all tailored to that community's needs. The community chooses its preferred options in a process that aims to be as participatory and inclusive as possible, encouraging women and more vulnerable groups to participate.

### **How can a village become climate-smart?**

The process of implementing the CSV approach is simple.

First is a "baseline assessment", which is understanding the problem. This is done in a participatory manner, taking in the concerns and local knowledge of all the stake holders in the cycle. Historical climate data is analyzed to assess the risks and long-term suitability of the main cropping and livestock/fishery systems.

The next step is all about constructing the right basket of solutions—a portfolio of practices and technologies that will address food security, adaptation, and mitigation that need to be tested in the CSVs. "Typically this includes interventions which are water-smart, weather-smart, seed/breed-smart, carbon/nutrient-smart and/or market/institution-smart. All of these interventions are site-specific and are chosen after extensive discussion with women and men farmers/fishermen, local governments and researchers.

Once the plan is in place, the ground is set for creating evidence for other areas with similar conditions, problems and constraints. This is the real test of theory and on-the-field realities, and bringing all farmers/fishermen on board is critical. And finally, the scaling up of useful technologies. Once intervention portfolios are successfully tried and tested, the evidence is used to contribute to scaling promising innovations.

This is done in two ways:

1. Farmer-to-farmer (or fishermen-to-fishermen) learning through self-help groups or associations. Messaging from a trusted source is the most effective way to spur farmers/fishermen to adopt new technologies and practices.
2. Sharing CSV research and lessons to influence large-scale CSA investment plans, promote mainstreaming of institutional changes, and inform policy instruments.

### **Case study from Karnataka**

As per the concept of CSV, selection of most suitable villages for the study is most important. Historical database and surveys to understand the severity of problem is the most important phase.

According to the studies conducted by National Institute of Oceanography, mean sea-level-rise trends along the Indian coasts are about 1.30 mm/yr and future projections (global) indicate about 0.48 m (A1B) by the turn of the century. Saltwater/freshwater interface moves further inland which is causing the reduction and extinction of estuarine associated habitats and ecosystems. The estuaries are becoming more saline due to sea level rise and the low influx of fresh water from catchment due to various anthropological and climatic factors. This poses a very serious livelihood issue for the coastal population, depending on the estuarine fishery

The Energy Research Institute (TERI), India projected a map of coastal areas of vulnerability with 1 m rise in Sea level (by constructing weighted index). According to the study the coastal areas of Karnataka have highly vulnerable and moderately vulnerable regions.

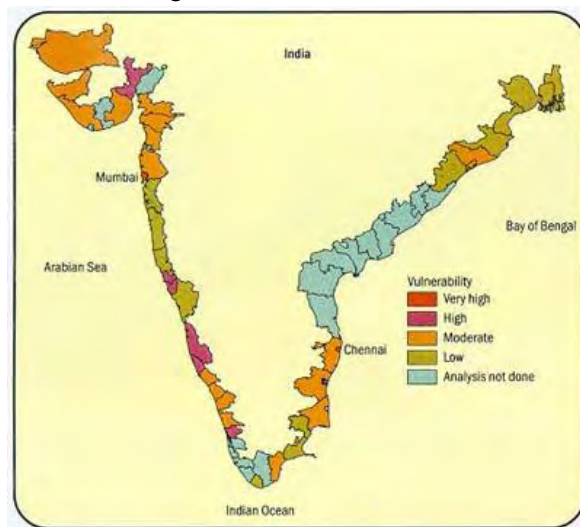


Figure 1. Vulnerability of coastal districts of India to sea level rise

To understand the holistic impact of climate change in Karnataka exhaustive surveys were carried out in coastal Karnataka. Karnataka's coastline stretches for 320 kilometres and consists of the three coastal districts namely, Uttara Kannada, Udupi and Dakshina Kannada. Of these, Uttara Kannada has 160 kilometre long

coastline, Udupi district has 98 kilometres coastline and the rest 62 kilometre length of coastline falls in Dakshinakannada district.

The vulnerability index of the three coastal districts of Karnataka were analysed by the method described by Dwarakish *et.al*, (2009). The five most important climate parameters such as demography, infrastructure, occupation, climate and fishery were used for the construction of the vulnerability index. It could be observed that, Udupi district has the highest vulnerability index of 0.460, followed by Dakshina Kannada with an index of 0.418 and Uttara Kannada with the lowest index of 0.362 (fig.2). Udupi district is vulnerable to accelerated sea level rise (SLR) due to its low topography and due to its high ecological significance.

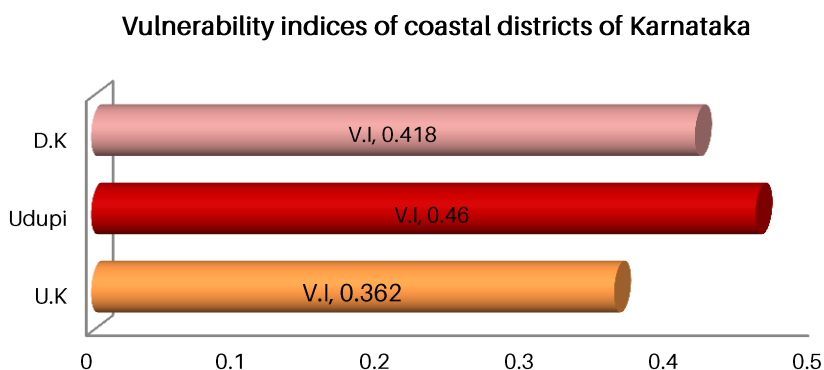


Figure 2. Figure showing the vulnerability Indices of three coastal districts of Karnataka

### Selection of district

Based on the results of Integrated District Level Adaptation and Mitigation (IDLAM) studies, Udupi district was selected for developing CSV. IDLAM studies were carried out based on secondary data such as historical data on extreme weather events, sea erosions, loss in fishing days. Forty six kilometres of the total 95 km stretch of Udupi's coastline is under critical coastal erosion and sea water intrusion. Besides this, studies have revealed that, 59 per cent of the 95 km of shoreline of Udupi district is at a very high risk due to future sea level rise. (SLR) Besides, secondary data collection, Participatory Rural Appraisal methods (PRA) and Rapid Rural Appraisal (RRA) methods were used for the selection of the district.

### **Selection of the Village**

For successful demonstration of climate smart technologies, willingness of both farmers/fishermen and local government to participate in the project is the major criteria. CMFRI have demonstrated various technology and Tharapathi village in Byndoor was found to be most progressive village, highly receptive to all the technologies extended to them.

Tharapathi Village in Byndoor is a progressive fishing village with fishing coastal hamlets Karkikali and Alvekodi. Hamlets are having scenic beauty a combination of clean water body in the sea and also with estuary of Suvarna River. Alvekodi, one of the northern hamlets at the mouth of Suvarna River is a hamlet with active fishing and fish landing areas, long and clean beach extending to river mouth. Greenery is mainly formed by coconut plantations and rich assemblage of mangroves. Most of the coastal fishermen thrive on coastal fishing and estuarine fishing. In earlier years the fishing was highly profitable venture and by year 2000, Alvekodi rose to a status of one of the most progressive village with organized fishing sector adopting self-regulation to ensure overall development.



### **Problem identification**

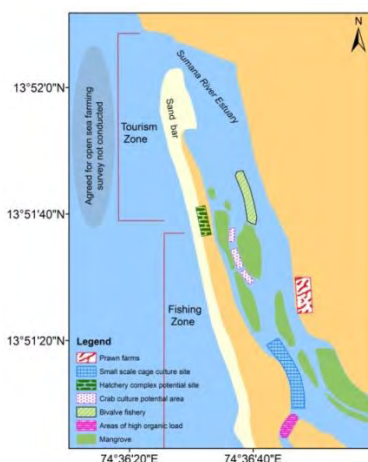
#### **Fishery related issues**

From year 2000 onwards low returns from the fisheries was felt as a major problem for the fishermen from the year 2000 onwards and it was found that estuarine fishery is totally collapsed. CMFRI has taken up scientific analysis of the issue of low catch from the sea and estuaries and found that heavy competition for limited resources in the sea is a major reason for reduction of catch per fishing units. Increasing number of fishing boats lead to low profitability. For understanding the reasons for the collapse of estuarine fishery, environmental studies were carried out and one possible reason observed was increased salinization of estuary, a reason for the fishery collapse of true estuarine species

like lady fish. Apart from the rainy time the salinity in the statuary remains more than 30ppt.

### Measures for fishery resource enhancement:

CMFRI wanted overall development of the village, with peaceful co-existence for which GIS based Marine Spatial Planning concept was introduced for the first time in India with making spatial zonation for different activities in coastal and marine area of the village in which the areas were marked for fishing, marine cage farming, estuarine aquaculture zones, tourism activities and also are designated for aquaculture compile for envisaging future multi species seed production/ rearing area.



Economic use of mangroves as a supporting activity to give awareness of mangrove protection also included in the MSP in the MSP.

To increase the fish production from the fishing village, alternate fishery enhancement techniques were introduced in 2007. During 2008-2009, marine cages were experimented sea of Tharapathi Village involving most of the fishermen families from this area. Rearing fishes in open waters was the first exposure of such knowledge to the fishermen which revolutionaries the thinking of fishermen population in fish production. The experiments with seabass farming in sea and their hands on experience in the daily cage maintenance activities gave them the confidence to take up the fish culture as an alternative vocation.





Looking at the invest capacities of fisherfolk of the village. CMFRI have taken up the responsibility of providing demonstration and popularization of customized cages which can be further fabricated and operated by fishermen as a family occupation. Along with production increase, utilization of the sea water dominated estuarine arise which showed very low productivity due to climate change induced sea level rise was important motive with this customized cage introduction in estuaries.

First demonstration of the customized cages with CMFRI design was demonstrated in northern part of Tharapathi village in which all fishermen of the village were given hands on training in cage fabrication, cage maintenance in all procedures till harvesting and marketing.



The fishermen of the village showed extra ordinary skills in improving feasibility and production and the fish production per cage have risen to 1 ton/cage (6mX2mX2M) for one year 3.2t per cage in 20 months. This is the highest production reported from seabass farming in India and the fishermen of the village deserve appreciation and they should be made to feel the importance of their achievement.

Encouraged and empowered by the CMFRI customized cage demonstration, first cage made of Netlon was introduced in Alvekodi estuary by a group of fishermen and at present we can see more than 100 cages of different dimensions managed by fishermen of the estuaries.

The success story of the village has attracted media attention and all important print media and visual media including Doordarshan telecasted the success story with great importance. Production from first demonstration cage was 400kg of Seabass and 200 Kg of red snapper which fetched a total revenue of Rs. 1.8 lakhs. In 2017 the fish production from the estuary was 20 t (from about 80 cages @ 250kg).



Improving the self-esteem of the fishermen was found to be a major catalyzing factor for the technology transfer and acceptance and for boosting the self-esteem of the fishermen harvest meals felicitating the fishermen were conducted time to time by inviting very reputed personalities from various walks of life. The boosting of their self-esteem at different phases led to revolution in fish production from small scale cages.



Low productivity per cage was due to non-availability of sufficient seeds to stock in full capacity of cages and the value realized for the production in 2017 was 80 lakhs. Fish cutting waste from fish cutting centres, Fishing harbours and hotels

were routed to the village for feeding fishes. Insufficient seed availability is the major limitation for higher production.



To increase the production from the limited water body the concept of “multi trophic aquaculture” was introduced in the Village in which green mussels were grown along with fish culture cages and further to improve production seaweeds also introduces in the finfish cages as a future avenue to be looked up on to produce more income from a limited water body. To sustain the production from these customised cages without environmental and disease problems, the carrying capacity of the estuary was estimated with scientific methodology.



The carrying capacity for the estuary was estimated to be 50 cages of 6mX2mX2m dimension with a stocking density of 12,000 seeds. Anticipated production from these cages will be 1 t. If well managed the production from the estuary per year is estimated to be 50t, 20 t more than present production with substantial reduction of existing number of cages. As per the studies conducted any increase in number of cages (above 50numbers) will lead to lower production and lead to environmental and disease problems.

Sea weed farming was introduced as an alternate vocation to improve seaeweed production from village and also to improve the livelihood avenues. In

carbon sequestration context also the seaweed farming was proposed as a possible technology for immediate future.

### **Problem identification of issues apart from fisheries**

#### **Scarcity of drinking water**

Scarcity of drinking water was the major problem pointed out and rain harvest methodologies were introduced in a limited manner. Low returns from the fishery are projected as major outfall of climate change and awareness regarding alternate vocation was an immediate requirement.

The fisher women who were involved in daily routines of fish collection, fish carrying and also in fish sales were turned jobless and the income generated through the fishing related activity is totally stopped during last few years. Rain harvest system was introduced and Officials from NABARD and Ministry of Environment and Forest were brought to the Village for further plans for improving water scarcity issues in futuristic perspective.



Project formulation with NABARD support is under preparation.

#### **Lack of awareness about alternate Vocation for coastal families**

Looking at the present status and future pressure CMFRI conducted a workshop introducing alternate vocation in which all members from the house can be participated. Officials from agriculture/ horticulture/ livestock/ fisheries departments and KVK resource persons explained the possible activities to be taken up for increasing the income from alternate sources so as to keep the fishermen diverting for unskilled sectors in urban areas by empowering them in alternate income generation possibilities.

During the discussion in the workshop, the coastal people were given an opportunity to express their interest in different activities explained in the workshop and a farming groups were created. As an immediate follow up of the workshop the coastal fishermen households having coconut plantations were made into Society and the society was registered in the agriculture department and free fertilizers were provided to these cooperative under State government schemes.



The workshop created lot of interest in coastal population especially women folk in the village. They showed their interest in making for alternate livelihood and the immediate action planned was horticulture development and poultry. Since the land area is limited, grow bag based vegetable farming was planned and the seeds of Tomato, Chilly, and Brinjal were grown to sapling stage from at nurseries and farms of Department of Horticulture Brahmar and it was transported to Alvekodi. 20 grow bags each were distributed with saplings of these plants and also seeds planted of 4 different gourd varieties.

Since the poultry farming also can be done in limited area chicks of two fast growing varieties "Giriraja" and "Suvarna Dhara" grown by Department of Poultry Department of Karnataka with 10 chicks each were distributed to coastal fishermen. Vegetable production from the village increased substantially. Poultry also helped in improving income level.





### **Achievements so far**

The biggest achievement so far is the empowerment of fishermen to alternate livelihood vocations, making them self-confident in taking up alternate vocations. The fish production through cages improved financial status of the fishermen and many of the fishermen who were about to leave villages due to lack of regular income could be used for the development of the village with alternate vocations. Due to low catch per boat operation the fishing intensity and engine capacity also were increased leading to high fishing pressure and high CO<sub>2</sub> emissions from fishing sector, the knowledge about the alternate vocations made some of them divert their fishing pressure for low carbon technologies like agriculture and horticulture farming and fish culture.

The villagers were introduced to the various authorities in government and non-government sector so that they can address their problems and get the possible solutions for their livelihood issues. They were exposed to various development schemes being organised by government and non-government sectors to make use of maximum use of the schemes. The major organizations introduced to the CSV were Department of agriculture/ horticulture/ livestock/ fisheries of Government of Karnataka, KVKs, non-governmental organizations like ATMA, NFDB, Officials from different commercial and cooperative banks, Officials from CRZ and ministries of environment and forest and Ministry of agriculture, policy makers like members of legislative assembly, suppliers of fish seed and fish feed, media like Doordarshan, various TV Channels, National and local print media etc. Alvekody hamlet of Tharapathi village is a well-known village in coastal Karnataka and the village is fighting hard to combat the vagaries being felt from climate change and low fish catch with adequate support from CMFRI and other organisations.

## Application of Information Communication Technology in Coastal Resilience through Income Improvement

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R.G. Ninan, V.H. Sajna, Dhanya Joseph and Grinson George  
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### Climate Change and Livelihood Insecurities of Fishermen Communities

Climate change and associated events such as cyclones, heavy rainfall and floods affects the fishers as well as fish farmers. Most significant impact of climate change is obviously on society, which deserves the utmost priority and attention. Societal impacts of climate change includes loss of fishing days, low value catch, damages to fishing equipment, damages to aquafarms and income loss cumulatively leading to livelihood insecurities among fishermen communities. The scenario adversely affects the national fisheries economy and many fishermen youth are forced to seek exit path from fisheries sector.

Climate change induced stock fluctuations and distribution results in catch composition variation and accordingly, catch of high value fishes may be replaced with low valued species, which in turn affects the profitability and income. At landing centres or harbours, they have to settle for low prices as they do not have any roles in further supply chain. Extreme weather events such as cyclones, depressions and associated phenomena negatively affects the fishermen community as they could not venture into sea, which results in loss of fishing days followed by a drastic reduction in income. The frequency and occurrence of extreme events are increasing, which exacerbates the aggrieved scenario of fishermen communities. Extreme events also damage coastal infrastructure, fishing equipments and even result in loss of life, thereby escalating the livelihood insecurities of fishermen folks. The impact of recent extreme event Ockhi on fishermen community is as tabulated.

Though many of the reported missing human lives returns, high risk prevails on the coastal livelihoods towards the occurrence of climate change related extreme events.

| S.No. | Items                                  | Tamilnadu   | Kerala  | Lakshadweep   |
|-------|--|---|---|---|
| i.    | Human lives lost (district wise)       | 30  | 75  | Nil   |
| ii.   | Livestock                              | 7654  | Nil   | 1691  |
| iii.  | No. of missing fishermen               | 203   | 141   | Nil   |
| iv.   | Houses damaged                         | Hut damaged- 6262<br>Pucca/kutchra houses partly damaged-101  | Fully-221<br>Severely-3253  | Fully-87<br>Partially -935  |
| v.    | Infrastructure Damage                  | <ul style="list-style-type: none"> <li>• Mechanized boats partially-640</li> <li>• Mechanized boats fully -60</li> <li>• Fiber Reinforced Plastic (FRP)Vallams partially-3407</li> <li>• (FRP)Vallams fully-3407</li> <li>• Electricity Board Poles - 15,858</li> <li>• Transformers-95</li> <li>• Fallen Trees -25,526</li> <li>• 38 Breaches in tanks and 31 Breaches in channels/canals</li> <li>• 103 Government buildings damaged</li> <li>• Damage to 75.046 km State Highways, 98.93 km National Highways, 417.18 km Rural/Urban Roads.</li> </ul> | <ul style="list-style-type: none"> <li>• Boats fully damaged/lost- 384</li> <li>• Loss of road- 41 km</li> <li>• Damage to Pumps - 180</li> <li>• Damage to Supply Tanks - 430</li> </ul> | <ul style="list-style-type: none"> <li>• Boats fully damaged/lost-12</li> <li>• Boats partially damaged-25</li> <li>• Houses - fully damaged-87</li> <li>• Houses partially damaged-935</li> <li>• Government building-340</li> <li>• Coconut trees - 32747</li> <li>• Other trees - 5514</li> </ul> <p>NIOT drinking water plant was also damaged to some extent</p> |
| vi.   | Coconut trees                          | -   | -   | 32747   |
| vii.  | Total crop area affected (in hectares) | 6625 hectares   | 7817.43 hectares  | -   |
| viii. | Damage caused to the environment       | The subject environment pertains to the Ministry of Environment & Forest, and their response is pending.  |   |   |

Source: Report No.211., *The Cyclone Ockhi - Its Impact on Fishermen and Damaged Caused by it*, Presented to Rajya Sabha on 4<sup>th</sup> April 2018 and Laid on the Table of Lok Sabha on 4<sup>th</sup> April 2018.

The marine farms of the nation are also in stressed condition due to changes in physico-chemical and microbial composition of the eco system, which in turn has detrimental effects on farm outcome. Irregular rainfall patterns and extreme events results in influx of flood and storm water into marine farms and consequently the species growth and maturity shall be reduced along with



increased susceptibilities to diseases and mortalities. The recent floods in Kerala are an example of the impacts of climate change on aquaculture farms. The composition of the aquaculture farms has been drastically changed due to the flood water intrusion. The cage farmers suffered extensive damages and wash away of their cages along with stock loss, thereby economic loss. The Chinese fishing nets, traditional fishing equipments were also damaged due to the flood.

The adverse impact of climate change associated events on fishermen and fish farmers are profoundly visible through multiple instances. In this context, coastal resilience strategies towards fishers and fish farmers income improvement needs to be highly prioritized and focused. Several alternative livelihood practices and avocations has been in practice across the nation among the coastal communities to cope up with the climatic adversities induced income loss. However, alternative livelihood practices and occupational changes away from the fisheries sectors shall not be sustainable options, as such scenarios eventually points out towards the exit path from fisheries sector. The challenge is to attain income enhancement and livelihood security by retaining the fisher folks in the fisheries sector itself and to make fisheries sector profitable for the prioritized stakeholders.

The harvest through Capture fisheries, Mariculture or other means after overcoming the climatic adversities deserves better profit, but in reality the fishermen and farmers are not yet earning the deserved profit tag. In spite of high price for fishes in market, the profit is being reduced within the supply chain and the farmers as well as fishers are gaining only low margin. Conventional strategies are focused mainly on availing high price for the produce. However, soaring fish prices is not an appreciable sustainable approach as fish is the common man's nutritional source. To attain village level nutritional security to millions, the fish price should be affordable. Again the challenge is to formulate a win-win approach with fishers and farmers earning higher profit along with moderate fish price for consumers.

### **Resilient Strategy through ICT application**

Fishermen or fish farmer community centric resilient strategy is the need of hour to attain income improvement and to negate the coastal livelihood insecurities. The fisheries supply chain operates through producers, marketers and consumers. Fishermen or farmers upon catch or harvest normally depends mainly on the auctioneers or wholesalers, who fix the price for the produce. However the fishermen and farmers does not have any significant role in further marketing and the price of their catch is determined within a shorter time frame,

which shall not be the deserving considering their efforts, uncertainties and adversities. Fishermen and fish farmers are provided with no other opportunity than to depend on wholesalers and physical market. To enhance the profit and income for fishermen and farmers, a feasible strategy is to empower them (Producers) to advance through the supply chain and accordingly they could have greater role in marketing as well as sales also, which in turn shall fetch them better profit margins. To attain the same and to reduce the sole dependency on middlemen, alternative marketing and sales channel needs to be developed to directly connect the fishermen or fish farmer communities with customers.

Technological interventions have the potential to reduce the process costs and the E-Commerce technology had proved across several sectors as an efficient solution to connect between the producers and consumers with beneficial implications on pricing and profits for both. E-Commerce is an online platform where producers have opportunity to effectively market their products towards a successful sale, after which associated distributor shall deliver the product to customer. Though E-Commerce is gaining popularity in fisheries sector, most of them are being operated by private entrepreneurs and the profit is being channelized to them than to producers. Multivendor E-Commerce platform is similar to a virtual market place, through which multiple vendors can make direct online sales to customers through online portal.

Fishermen groups could be trained to familiarize with the e-commerce solutions and empower them to harness the beneficial implications towards advancement in supply chain, direct marketing and sales. Fisheries institutes could play lead role in transforming the roles of fishermen or fish farmers through multivendor E-Commerce solutions. However besides offering e-commerce platform, continuous support needs to be provided to make the venture success. Pilot studies, capacity building programs and promotional activities are of need to make impact of technology in societal transformation.

#### **NICRA Intervention: Multivendor e-commerce website and associated mobile application**

In the context of climate change adversities on fishermen communities and in line with the highly prioritized national goal of income improvement for farmers, National Innovations on Climate Resilient Agriculture (NICRA) project of Central Marine Fisheries Research Institute (CMFRI) has developed a multivendor E-commerce website hosted as [www.marinefishsales.com](http://www.marinefishsales.com) and associated android mobile phone application 'marinefishsales' for enabling direct sales between

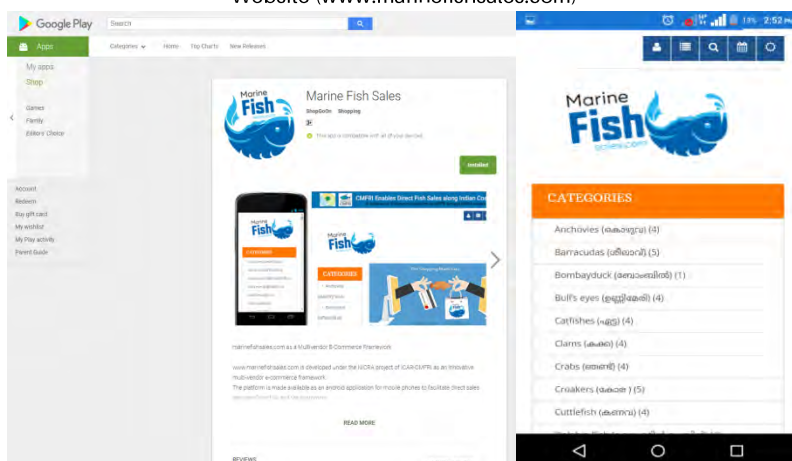
fishermen and customers. Developed multivendor e-commerce platform focuses on income enhancement for coastal fishers and farmers.

## Innovation

The innovation incorporated is that, in contrary to typical e-commerce ventures where single firm or company as major profit beneficiary, the developed e-platform envisions multiple fishermen self-help groups (SHGs) as beneficiaries. This may be the first instance that a Govt. institution in fisheries sector facilitates the E-Commerce solution, thereby undertaking the greater role to address grass root level climate change adversities through income improvement and livelihood security improvement.



Website (www.marinefishsales.com)



Android Mobile Application 'marinefishsales'

### **Trainings through NICRA project**

Besides multivendor e-commerce solution development, multiple trainings were organized at CMFRI, Kochi through NICRA project to familiarize the developed e-commerce website and mobile app among fish farmers and 28 participants (farmers, fishermens, SHGs and traders) underwent training. On the next level, trial sales were done to familiarize the operational modalities of the e-venture. Farmer meet were arranged on to fix minimum base price, above which only sales shall be performed. Trial sales were further carried out after which sales to public were initiated. Training on 'Fish processing and Packaging for E-Marketing' were also arranged at KVK Njarakkal. Distributers have been engaged to facilitate distribution in case farmers do not have distribution facility. Trial sales have ensured functionality of multivendor e-commerce website. Customization of website and app has been done regarding direct sms to vendors upon each order. Multistore feature has been enabled to replicate the model across other coastal regions of the nation.

### **Features of the E-platform**

The platform is an interface with administrative control panel, vendor panels and user storefront with ICAR-CMFRI in an administrative role, multiple coastal fishermen SHGs as vendors and consumers as users. Various fishermen SHGs can register as vendors (fishers and farmers) based on their fish products and update their stock availability under pre-approved categories and products, which shall be displayed in the website and associated mobile app. Customers visiting the website or app could place the order with payment options of cash on delivery, net banking or with debit/credit cards and subsequently the registered vendor shall be notified through email and SMS, upon which the quality products within the pre-assigned time frame shall be delivered, enabling direct product sale between customers and SHGs. The profit could be shared directly among the fisherfolk SHGs thus ensuring income improvement for fishermen groups.

Each fish vendor group shall be provided with unique login credentials along with vendor panel through which products (raw, cleaned, sliced, bulk, portions, etc) could be added or modified. Unlimited categories and products, auto stock reduction, printable invoice, sales reports, email and sms notifications, special prices and discounts etc are other interesting features of the website. Customers through store front could select or search for products under various categories, proceed to checkout, fill customer details and confirm order. Customers shall

receive sms notifications and call from vendors on the status of order processing. Options are enabled for customers to add review on the products purchased.

### **Current Status**

Around 35 fishers/farmers registered in the website as vendors and trial sales to public are ongoing with total sales amounting to around Rs.89, 000 (Rupees Eighty Nine Thousand). Steps shall be taken to scale up the sales and to extent the beneficiaries. Govt. of Himachal Pradesh expressed interest to implement the same in their state with technical guidelines from NICRA team of CMFRI, which was readily agreed upon. Govt. of Himachal Pradesh has announced in their state budget speech regarding implementation of the same.

### **Lessons learned and Way ahead**

The pilot/ trial sales through the portal and mobile app had gained us several valuable insights, which shall be of high significance in upscaling of the technology.

Multivendor E-Commerce solutions could be an effective solution towards income improvement for coastal communities. Self Help Groups needs to be created towards incorporation as vendors for direct sales through the e-platform. Vulnerable groups related to climate change needs to be prioritized. Initially the sales shall be of low volume and at such instances institutional support in terms of monetary or advertisements could be considered. To ensure uniformity and competence trainings are essential. Vendors need to obtain FSSAI registration and other legal compliances. Each associated vendors need to develop their own brand name, as it shall gain more customer confidence and professionalism in procedures. A dedicated distributor group with order management shall be more feasible. However the price of the stock needs to be fixed by farmer or fishermen and distributor should be eligible only for margin per order or per kilogram sales. Customer pooling or pre orders could channelize more bulk sales. Extensive orientation program needs to be carried out to extend the grass root level beneficiary groups. The program needs to be extended through fisheries institutions of the nation to bring transformation and scalability.

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**Introduction**

India is endowed with a long coastline of 8129 km. Being tropical country, the marine ecosystem bordering Indian sub-continent contain large number of species adapted to wide range of habitats, from mangrove swamps, estuaries, saline lagoons, sea grass meadows, sandy/ muddy/rocky coasts, coral reefs, oceanic islands to deep oceanic realms. These resources are supporting the marine fishery of the country. The water spread of continental shelf is 0.5 million sq. km and of EEZ is 2.02 million sq. km. The annual catchable marine fishery potential of the EEZ is 4.42 million tonnes. India is one of the leading nations of the world in marine fish production and export.

**Growth in Marine Fisheries**

Coastal marine fishery made remarkable growth since mechanisation started in early sixties. The marine fish production increased steadily from 0.5 million t in 1950 to a high of 3.94 million t in 2012. This increase can be attributed mainly to the increase in fishing intensity coupled with introduction of mechanised fishing vessels, motorisation of the country crafts, modernisation of harvesting techniques coupled and extension of fishing to deeper waters. Mechanisation and diversification of fishing have slowly extended fishing activity beyond the continental shelf. Adoption of advanced techniques to detect resources and to identify productive ground and use of fish aggregating devices added to the efficiency of fishing operation.

**Marine Finfish Resources:**

Finfish resources are classified broadly as pelagic and demersal based on their distribution in the water column. Pelagics are diverse group of small to large fishes which occupy mainly the surface and subsurface layers of the water column. Most of them are characterised by their shoaling behaviour. Large

numbers of species which are either bottom dwelling or inhabiting mainly along the lower layers of water column are termed as demersal resources.

Pelagic fishes in the marine sector, includes shoaling fishes like sardines, anchovies and mackerel which concentrate in coastal pelagic zones as well as solitary fishes like billfishes and sharks that occur in the oceanic waters beyond the continental shelf area. Pelagic fishes contribute more than 50% to the total marine fish landing of the country. The Oil sardine (*Sardinella longiceps*), Indian mackerel (*Rastrelliger kanagurta*), Ribbonfish (*Trichiurus lepturus*) and Bombay duck (*Harpadon nehereus*) form major single species fisheries. The other major group were the lesser sardines, carangids, seerfishes, billfishes, king fish, mahimahi and Barracudas.

### **Oil sardine**

The resource is represented by a single species, *Sardinella longiceps* and distributed widely along the Indo-Pacific region. They form the mainstay of pelagic fishery of the country. Till recently their abundance was largely restricted to the coastal waters between Quilon and Ratnagiri with 90% of the fishery from this area alone. However, in recent years, they are emerged as a major resource all along the east and west coast.

Annual exploitable stock of the resource is estimated at 510,513 tonnes. However, their production was 4, 62,976 t during the last decade (2003-2012), with largest production of 720,250 t during 2012. They constituted 15.1 % of the total marine fish production of the country during this period.

### **Lesser sardines**

Nearly 13 species constituted the resource and fishery. They occur along the entire Indian coast but their abundance and fishery confined largely to the inshore waters of Kerala, Tamilnadu and Andhrapradesh. It includes 10 species under the genus *Sardinella*, two species under *Dussumieria* and *Esculosa thoracat*. Dominant species are *Sardinella gibbosa*, *S.albella*, *S.fimbriata*, *S.dayii* and *S.sirm*. Species show discontinuous distribution.

Annual exploitable stock of the resource is 116,641 tonnes. The present average production was 102,361 t during the decade. They constitute nearly 3.3% of the marine fish production during this period.

### **Wolf herrings**

They are non-shoaling fishes, abundant along both east and west coast with large abundance along the southeast coast. Two species namely, *Chirocentrus dorab* and *C.nudus* supported the resource and fishery. Their major abundance

is in shallow waters between 10 –30 m depth. They migrate to deeper waters for spawning. They usually form fishery along with other resources. Their average annual landing is 18,403 t during the last decade, forming 0.6% of the total marine production. 50% of the total landing is from the Tamilnadu coast between Palkbay and Gulf of Mannar. Annual exploitable stock of the resource is 20,732 tonnes

### **Anchovies**

Resources and fishery are supported by species belonging to the genera *Stolephores*, *Thryssa*, *Thryssina*, *Coilia* and *Setipinna*. White bait belonging to the genus *Stolephores* constitutes nearly 70% of the catch. They are abundant in coastal waters of 5-20 m depth. 90% of the resource was concentrated in area between Ratnagiri and Gulf of Mannar. Abundance of other anchovies is relatively large along the coastal waters of Andhra, Tamilnadu, Kerala, Karnataka and Maharashtra.

Their exploitable potential is 147,695 t. Present level of production is 131,606 ton during the last decade. They form nearly 4.3% of the marine production.

### **Other clupeid fishes**

Several species belonging to different genera, *Pellona*, *Hilsa*, *Ilisha*, *Elops*, *Megalops*, *Anadontosoma* etc. support the fishery. They are widely distributed along the east and west coast, with large abundance along the east coast.

Potential yield of the resource was 67.626 t. Present production ranged between 61,491 t during the last decade. They constitute 2% of the total marine fish production.

### **Mackerel**

Resource is represented by three species in Indian waters. However more than 98% of the stock and fishery was supported by Indian mackerel, *Rastrelliger kanagurta* alone. *R.brachisoma* and *R.faugni* form sporadic fishery respectively in Andaman Madras waters. Mackerel is abundant in coastal waters within 25 m depth. Nearly 80-90% of the total mackerel catch is from west coast. However in recent years, their abundance and fishery is on the increase along east coast. Annual exploitable potential is 204,596 tonnes. The present average production was 176,103 t during the last decade and constitutes nearly 5.7% of the marine fish production during this period.

### **Tunas**

These are typical oceanic fast swimming and highly migratory pelagic fishes and most of them have cosmopolitan distribution. Resource is represented by nine



species belonging to the genus *Auxis*, *Euthynnus*, *Thunnus*, *Katsuwonus*, *Sarda* and *Gymnosarda*. These are typical shoaling fishes and aggregate in large numbers around any floating objects in open sea.

Their annual exploitable potential is 268,883 tonnes. The present average production was 60,590 tonnes during the last decade and constitutes nearly 2% of the marine fish production during this period.

### **Seerfishes**

They are the most relished fishes with very high market demand. Five species namely *Scomberomores commerson*, *S.guttatus*, *S.lineolatus*, *S.koreanus* and *Acanthocybium solandri* supported the resource and fishery. They are abundant in the neretic and oceanic waters of both coasts. But undertake long term inshore migration and form fishery in shallow waters. *S.guttatus* is available in less saline turbid waters of coastal belt. Annual exploitable stock of the resource is 75,078 tonnes. Average production was 50,450 t during the last decade and constitutes nearly 1.6 % of the marine fish production.

### **Billfishes**

Bill fishes form by-catch in oceanic tuna and shark fishery. They are represented by *Istiophores*, *Makyras* and *Xiphias* Spp. Their annual exploitable stock is 13,486 tonnes. Their average production was 6,372 t during last decade. They constitute only 0.3% of the marine fish production during this period.

### **Bombay duck**

The Bombay duck or bummalo (*Harpadon nehereus*), is a lizardfish. Adults may grow to a size of 30-35 cm, but the usual size is around 25 cm.

They enjoy a discontinuous distribution along the Indian coast, with abundance along the northwest and northeast coast. It has been traditionally caught in the waters off Maharashtra and Gujarat along west coast and west Bengal and Orissa along the east coast. The fish is often dried and salted before it is consumed, as its meat does not have a distinctive taste of its own.

### **Carangids**

Carangids are a diverse group of fishes having different body shapes. They are widely distributed along the entire coastal waters of India, Their major abundance confined to shallow waters up to 60 m depth. More than 35 species constituted the resource, with many species showing discontinuous distribution. However, commercial fishery was supported by few species. Horse mackerel and scads dominated the fishery. Annual exploitable stock of the resource is 232,313 tonnes. Average production was 200,324 t during the last year and constitutes

nearly 6.5% of the marine fish production.

### **Ribbonfishes**

They are abundant along east and west coast with large abundance along the peninsular region. Resource was supported by six species dominated by *Trichiurus lepturus*. Their maximum abundance was reported in deeper waters between 25-75 m depth. Being carnivores they follow shoals of small pelagics and Acetes and were fished in large quantities by shrimp trawls. Annual exploitable stock of the resource is 243,210 tonnes. Average production was 168,853 t during last decade and constitutes nearly 5.5% of the marine fish production.

### **Belonid fishes**

They inhabit off shore waters of 30-40 km away from the shore Good resource of garfishes, half- beaks and flying fishes were available in the Gulf of Mannar and Palk Bay and support a potential local fishery. Fishery was supported by several species Flying fishes were supported by species belonging to genera *Parexocoetus*, *Cypselurus* and *Exocoetus*. Good fishery occurs along the Coramandal and Gulf of Mannar coast of Tamilnadu and small quantities from Andhra coast. Annual exploitable stock of the resource is 10,067 tonnes. Average production was 1,825 t during last decade.

Half and fullbeaks resources supported good fishery in the Gulf of Mannar and Palk Bay. Their, annual exploitable stock is 11,624 tonnes. Average production was 4,140 t during last decade.

### **Other pelagics**

Other resources which contribute considerably to pelagic fishery are barracudas, king fishes, mahi mahi Bombay ducks, myctophids etc. They form commercial fishery at varying levels at certain areas

Marine fishery has made rapid changes with motorisation of traditional crafts and introduction of mechanised fishing units coupled with wide use of innovative gears and methods in line with mass harvesting technologies. With the growth of coastal marine fisheries and ever increasing demand from domestic and export markets, fishing pressure has increased on the limited resource. Tropical resource being multi-species and co-exist in the same area, effect of fishing is felt not only on the target groups but on other resources also. The peculiar nature of resource combination made the task of adopting a harvesting technology which will harvest only selected resource totally impossible. With rare exception of few

gears almost all gears or methods in one way or another harvest one species or another from different habitats at their different pace of life. But the extent and degree varies.

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## Introduction

Climate change has been recognized as the foremost environmental problem of the 21<sup>st</sup> century and has been a subject of considerable debate all over the world. Climate change is predicted to lead to adverse, irreversible impacts on the earth and the ecosystem as a whole. Specific weather events are difficult to connect to climate change; global warming has been predicted to cause broader changes, including melting of glaciers, arctic shrinkage and sea level rise. Climate change has the implication of mass mortalities of several aquatic flora and fauna, including sea weeds, sea grasses, finfishes, shell fishes, corals and mammals.

in 2007, the International Panel on Climate Change (IPCC) has been highlighted various risks to aquatic systems from climate change, including loss of coastal wetlands, coral bleaching and changes in the distribution and timing of fresh water flows. The uncertain effects of ocean acidification will also profound impacts on marine ecosystems and in turn to mariculture also (Orr *et al.*, 2005).

There are physical, chemical and biological hazards of climate change on aquaculture.

## Physical hazards

- i) **Temperature anomalies:** Higher air temperatures and an increased frequency of hot days and nights, heatwaves and abnormally cold events are more likely to occur. Fish stock performance (e.g. Growth, survival) and therefore productivity is affected by surface air temperature anomalies. Bu the effect could be advantageous for some farmed species.

- ii) **Sea surface temperature changes (SST):** Each and every marine species is adapted to a particular temperature range in the environment. In mariculture, a change in SST may put some production systems at risk if the increase or decrease in temperature exceeds the optimal range for survival or growth.
- iii) **Precipitation anomalies:** Likely increase in the frequency and intensity of heavy rainfall events on one hand, and a prolonged absence of precipitation on the other can impact mariculture productivity. Productivity is adversely affected by unforeseen changes, especially from erratic rain fall patterns.
- iv) **Rising sea levels:** Sea levels are expected to increase more than the current IPCC projections, and the penetration of saline water to inland areas could result in some freshwater production systems unsuitable for the culture of such species. Wave surges and inundations also would lead to alteration of habitats of farmed species, eroding coastal strips or submerging coastal areas.
- v) **Floods:** Flooding caused by abnormal heavy rainfalls – but often exacerbated by poor planning or the absence of coordinated action by different agencies – may become more severe as a result of global warming, rendering farming systems, input sources such as wild seed, and plant-based feed ingredients more vulnerable.
- vi) **Drought:** Could be possibly more intense, or of longer duration, or both. The risks associated with drought are not well understood compared to those associated with floods or cyclones. The impact of drought can only be partly attributed to deficient or erratic rainfall, as drought risk appears to build up over time as a result of a range of drivers. These include: poverty and rural vulnerability; increasing water demand due to urbanization, industrialization and the growth of agribusiness; poor soil and water management; weak or ineffective governance; and climate variability and change (UNISDR, 2011).
- vii) **Cyclones:** The growing intensity of tropical cyclones can cause the widespread destruction of infrastructure and the disruption of services that affect aquaculture production. Cyclones can delay the resumption of farming activities, and disrupt activities along the other segments of the value chain (seed and feed production and supply, post-harvest, transport and marketing). Cyclones also cause the silting-up of molluscs growing areas.

### Chemical hazards

- i) **Lower pH values (acidification):** A number of studies have shown that lower pH values affect the development of shells of molluscs and corals.
- ii) **Salinity changes:** Salinity may increase or decrease depending on changes in precipitation and evaporation. In coastal waters this arises by virtue of the heavy influx of floodwaters from rivers and estuaries. In rivers, changes are caused by the intrusion of seawater.
- iii) **Low oxygen levels in culture waters:** An increased impact of upwelling of anoxic water results in low oxygen levels. Plankton respiration gets intensified as a result of higher temperatures. Eutrophication also occurs at many instances.

### Biological hazards

Biological hazards are driven by physical and chemical factors:

- i) **Eutrophication:** Rising temperature levels are likely to cause wide fluctuations in the thermal dynamics of water bodies, including increasing stratification and nutrient circulation, with implications in primary production and hence higher trophic levels. More intense eutrophication and algal blooms will have implications in local aquatic ecosystems and in aquaculture, especially in static water bodies like lakes and reservoirs.
- ii) **Harmful algal blooms (HAB):** Increase in temperatures, increase in frequency and extent of algal blooms, and changes in the diversity of zooplankton have been observed in semi-enclosed seas. This will cause severe financial implication as an offshoot of a biological hazard.
- iii) **Pathogens and parasites:** Increase in prevalence, a shift in the distribution of pathogens and parasites, enhanced growth and reproduction of microbes are also biological hazards of climate change.
- iv) **Pollution:** increase in pollution toxicity, including the dilution of micro-plastic as a result of rising water temperatures is another hazard that affect fisheries and mariculture.

### Impact of climate change on Aquaculture

The main climate change related drivers – warming of water bodies, rising sea levels, acidification of the seas, changes in weather patterns and extreme weather events – have direct and/or indirect impacts on aquaculture, and the evidence of such impacts has been well documented (FAO, 2009). The links between each driver and its impacts on aquaculture have been broadly established by numerous studies, with varying degrees of confidence. The

predicted rise in seawater acidification will affect the physiology of bivalves both in terms of growth and reproduction, and may affect the quality of shells. On the other hand, warming can also increase spat fall and growth rates, as well as extend the latitudinal range of farming, which are positive effects. Indirect effects of climate change include changes in circulation patterns and productivity in the sea (Brochier *et al.*, 2013) that will affect the production of fishmeal/oil; physical impacts affecting the production of terrestrial fish feeds; and physical impacts and adaptation in other sectors that negatively affect aquaculture, e.g. priority water use for agriculture under climate change. Many studies have examined the indirect effect of climate change on the spread and occurrence of disease in farmed aquatic organisms, in addition to shifts in the distribution of parasites and pathogens. Vibriosis, for instance, is one of the diseases that may be profoundly affected by climate change since vibrios grow preferentially in warm waters ( $> 15^{\circ}\text{C}$ ) and at low salinity ( $< 25$  ppm).

The impacts include:

**a) Biological:** An increased prevalence and virulence of pathogens as a result of higher levels of stress on cultured organisms; a shift in the distribution of pathogens and parasites; harmful algal blooms; the disruption of shell formation in molluscs and crustaceans; a disruption in reproductive patterns; shortage of fish meal and fish oil; reduced availability of natural seed; but also faster growth, higher feed conversion efficiency and higher yield from a higher temperature as long as it does not exceed the species' range of tolerance.

**b. Environmental:** The loss or alteration of habitat, eutrophication, harmful algal blooms, severe damage to corals, salinity intrusion – but also an expansion of the range of cultivation of some species.

**c. Social and economic:** the loss of arable land and culture areas due to salinity intrusion, coastal erosion and floods; the loss or disruption of livelihoods from the biological and environmental impacts, and from the loss of stock and destruction of physical structures; physical dislocation; increased public health problems.

## **Vulnerabilities**

### **Culture environment**

Many aquaculture systems are highly vulnerable to natural hazards. Sites are usually located in low lying areas; on areas that are fragile and ecologically sensitive and prone flooding; in water resources which may not hold sufficient water for floating cages or pens over a prolonged drought, and therefore become eutrophic; along rivers and estuaries that could dry up or be inundated with little warning. Coastal areas, and even enclosed or protected bays, are

invariably exposed to tidal surges and cyclones. Pond systems, whether brackish or marine, are susceptible to the effects of high temperature, erosion and siltation. Mariculture would be highly exposed to harmful algal blooms (HABs) and oxygen depletion from the upwelling of anoxic water.

**Species and systems:** Several approaches to assessing the vulnerability of species and systems are possible when devising institutional and structural adaptation strategies for farmers and at a local level. However, the most practical approach would probably be to categorize aquaculture units by geography – such as inland, coastal and arid – tropical – and then by farm density and production intensity. Within the same location and with the same farmed species, the combination of technology, farm management practice and area management could reduce the vulnerability of an aquaculture system.

With respect to a specific impact on a specific species, molluscs in coastal aquaculture are probably the most vulnerable to acidification. Pearl culture in the Pacific is the biggest export earner for the region; in 2007, pearl, giant clams and shrimp made up most of the US\$211 million total export value of aquaculture commodities from the Pacific region (Bueno, 2014). A rise in sea temperature and an increased acidification of the ocean would stress pearl oysters and could affect pearl formation. Pacific cyclones have time and again destroyed onshore and nearshore installations and growing facilities.

Farmed trout, of which 22 % is based on improved stocks, and farmed Atlantic salmon, 95 % of which derives from genetically improved stocks (Gjedrem and Baranski, 2009), would be vulnerable to direct impacts (i.e. temperature rise beyond a tolerable range) and the indirect impact of reduced availability of plant- and fish-based raw materials for feed (Troell et al., 2014).

A study in Norway has shown better productivity of Atlantic salmon with warmer seawater: on average, a percentage increase in SST increases the production level by about 9 % relative to no change in the sea temperature level; but the increase diminishes with increasing SST level (the effect is positive but diminishes as temperature rises). Furthermore, a higher temperature increases the bacterial density in the water and the frequency of algal blooms. Mortality rate will increase for all age groups. If the amplitude and/or average temperature increase to the level where the physiology of the fish is compromised, the probability of mortality rises. Global warming is counterproductive for the industry if the sea temperature increases too much (Lorentzen, 2008).



Tilapias would have a high resilience on a regional basis in subtropical and tropical climates. Several fast-growing strains, including salt-tolerant ones have been bred. The hatchery technology is relatively easy and inexpensive, and now widespread. Tilapias are known to be highly adaptable to a range of environmental parameters, and known for their ability to adapt to and compete with other species over a wide range of ecological conditions. Tilapias are among the most widely bred species for commercial production; they are farmed in 140 countries and territories, and account for nearly 7 % of world production of farmed aquatic animals, and more than 10 % of farmed finfish (FAO, 2016). As a species group, Cyprinids should also have a high resilience: comprising several species, it is grown over a wide climatic range is artificially bred and the broodstock and hatchery technology is widely adopted. Two species, bighead and silver carps, are largely non-fed. Carps are versatile and can flourish in a wide variety of habitats including those which are highly degraded. They can tolerate a wide range of temperatures and environmental conditions. They have a higher tolerance to low oxygen levels, pollutants and turbidity than most native fish, and are often associated with degraded habitats, including stagnant waters.

Furthermore, in the major producers such as Bangladesh, China and India, the predominant culture practice is polyculture of more than two species of carps, or of carps and other finfish species such as tilapia, *Pangasius* and *Clarias* catfish; it is a highly diversified culture system, which is generally recognized as resilient.

The high dependence of several developing countries on marine shrimp for export earnings and the high exposure of – mostly coastal – brackish water culture areas to many climate change hazards – coastal storms and tidal surges, flooding, erratic rainfall, and temperature anomalies – make marine shrimp culture highly vulnerable. This being said, in practically all the penaeid shrimp farming countries in Asia and Latin America a large proportion of the recurring and heavy losses have been from disease.

Utilizing a series of indicators of exposure, sensitivity and adaptive capacity in a GIS model, Handisyde et al. (2006) have been identified Bangladesh, Cambodia, China, India, Philippines and Viet Nam as the most vulnerable countries worldwide. Climate change could therefore prevent aquaculture from being a good source of nutritious food and livelihoods in these countries.

### **Climate change Adaptation**

Adaptation, defined later in this section, essentially involves four basic concepts: vulnerability, resilience, adaptive capacity and sustainable livelihood.

Vulnerability to climate change comprises a combination of exposure to climate change variables, sensitivity to those variables, and the capacity to adapt and build resilience to climate change. An assessment of vulnerability is usually seen as the first step in the adaptation process. A comprehensive discussion on Vulnerability Assessment is provided by Brugère and De Young (FAO, 2015).

- Exposure: the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes.
- Sensitivity: the degree to which a system is affected adversely or positively by climatic stresses. Some use “dependency” as a measure of how serious the impact would be on each of the attributes that determine the overall well-being of the system.
- Adaptive capacity: the ability of a system to adjust to climate change, to mitigate potential damage, to take advantage of opportunities, or to cope with the consequences. Adaptive capacity is context specific, as illustrated by aquaculture being located in fragile ecosystems in coastal, low-lying and highly exposed areas, and/or in a social context where farmers in an area have poor access to key services, or there is a lack of social cohesion, or where policies which aim to encourage investment in adaptation are absent or poorly designed.

Adapting to climate change essentially involves:

- (a) Reducing exposure,
- (b) Decreasing sensitivity, and
- (c) Strengthening adaptive capacity.

One of the most important factors that shape the adaptive capacity of individual farmers, farm households and farming communities is their access to, control over and ability to use natural, human, social, physical and financial resources productively, i.e. the livelihood capitals.

#### **Purposes of an adaptation measure and examples of management measures**

**Reduce exposure to climate hazards:** Conserve natural sea defenses, i.e. mangrove; Build/improve artificial river banks and sea defenses (seawall, embankment); Risk-based zoning (also considering longer-term changes) and site selection (for areas being developed for aquaculture); Raise and fortify pond dikes; dig deeper ponds; Implement safer, flexible and resistant cages, rafts and other holding systems; Upgrade pumps and sluices; Short cycle aquaculture techniques; closed aquaculture production system, i.e. recirculation aquaculture, aquaponics; Shift production units to less exposed areas, relocate;

Minimize fish stress, ensuring plenty of oxygen; facilitate and enforce safety-at-sea measures.

**Reduce sensitivity:** Farm more tolerant species to the important stressors i.e. temperature, salinity, acidification; Reduce dependence on wild-caught seeds; Reduce dependence on fish meal and fish oil; Reduce Feed Conversion ratios and improve feeding efficiency; -Diversify species or product range; Diversify livelihoods; Integrated farming systems.

**Increase adaptive capacity:** Better weather forecasting, water/environment monitoring, early warning systems; Improved disease surveillance systems; Insurance for crops and farm physical assets; Durable and reliable access assets i.e. roads, power distribution system, water supply system, communications system; Organize and professionalize farmers with the appropriate attention to gender, e.g. fostering women's associations; Establish networks, societies, cooperatives; strengthen social capital; Improve access to markets and fair trade; Fair employment rules and enforcement; Establish Aquaculture Management Areas; Improve access to training and improved technology; Promulgate clear and policies and regulations.

**Resilience:** The converse of vulnerability, resilience in the social-ecological context is the system's capacity to absorb recurrent disturbances in order to retain essential structures, processes and feedbacks (Adger et al., 2005). Resilient social-ecological systems incorporate diverse mechanisms for living with and learning from change and unexpected shocks. Disaster management thus requires multilevel governance systems that can enhance the capacity to cope with uncertainty and surprise by mobilizing diverse sources of resilience.

**Options:** Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods, as well as behavioral and lifestyle choices (IPCC, 2014). These enablers are expanded into a list of ten options under three categories, namely: structural/physical, social and institutional (IPCC, 2014).

**Spatial planning:** This comprises marine and terrestrial zoning for siting of aquaculture facilities (subtidal and terrestrial systems) and mangrove areas to balance aquaculture needs with terrestrial development and shoreline protection with rising sea level. In addition, the need to think long term about requirements for current coastal activities to shift landwards as shorelines retreat over time.

**Structural/Physical:** Engineered and built environment (e.g. seawalls and coastal protection); - Technology (e.g. genetic diversification, new farming systems and technologies, early warning systems and technologies etc.).

**Social (including resource management):** Educational (e.g. integration of awareness-raising into education with the appropriate gender focus); - Informational (e.g. hazard and vulnerability mapping, early warning system, community based adaptation planning, participatory scenario development); - Services (e.g. emergency services, social safety nets and social protection); - Behavioral (e.g. accommodation, retreat, migration, livelihood diversification, changing aquaculture practices); - Organizational (e.g. aquaculture area management under the Ecosystem approach to Aquaculture (EAA) (FAO and World Bank, 2015)).

**Institutional:** Economic (e.g. financial incentives including taxes and subsidies, payments for ecosystem services, insurance, microfinance); Laws and regulations (e.g. building standards, defining property rights and land tenure, marine-protected areas, farming and fishing quotas, ethical employment, appropriate incentives); - Government policies and programmes (e.g. mainstreaming climate change into national and regional adaptation/development plans, integrated coastal zone management, fisheries management, community-based adaptation, disaster planning and preparedness).

**The ecosystem approach to aquaculture (EAA)** is a crosscutting enabler – a strategy that can be implemented at different geographical and management scales – and considers climate change as a relevant external driver requiring adaptation measures. Such measures are included in the aquaculture management plans. The following tables (1 and 2) provide two perspectives on adaptation options. The first gives examples of specific impacts and the mostly structural and social adaptation options to deal with the impacts. The second is a broader, strategic classification of impacts on ecological well-being, human welfare and sector governance, and describes adaptation options that are mostly institutional and social.

#### **Potential adaptation measures**

- Shift aquaculture to non-carnivorous commodities
- Selective breeding for increased resilience in aquaculture
- Moving/planning siting of cage aquaculture facilities

- Change aquaculture feed management: fishmeal and fish oil replacement; find more appropriate feeds
- Ecosystem approach to fisheries/aquaculture and adaptive management
- Change aquaculture feed management
- Building aquaculture facilities to withstand increased storm damage
- Encourage native aquaculture species to reduce impacts if fish escape damaged facility

The following table gives a brief on the aquaculture systems on its impact and adaptation to climate change:

| Aquaculture system/culture environment | Impact +/- | Kind of impact   | Adaptation  |
|--|------------|--|---|
| <b>Driver: Temperature</b>             |            |  |   |
| Cage, pond finfish in all environment  | -          | Temperature rises above optimal range of tolerance; temperature dips below optimal range of tolerance.       | Breed for higher tolerance; short-cycle aquaculture; move production sites to lower altitudes/latitudes (in the northern and southern hemispheres according to temperature changes and trends); for pond systems, build deeper ponds                                      |
| All systems/all environments: finfish  | +          | Higher temperature could stimulate faster growth, higher yield.  | Intensify production; increase feed input; improve management practice; tighter control of oxygen availability.   |
| Marine, brackish- and freshwater       | -          | Increase virulence of otherwise dormant pathogens; rampant growth of parasites; shift in their distribution. | Monitoring of environmental variables as well as diseases and pathogens; tighter biosecurity measures in general (including early warning and better dissemination of information); increase investment in vaccines and other environmentally friendly prevention methods |
| Crustaceans and carnivorous finfish    | -          | Shortage of fish meal and fish oil   | Fish meal and oil replacement; shift to non-carnivores; better feed management practice.  |
| All fed fish                           | -          | Shortage of terrestrial feed ingredients   | Better feeds, better feed management practices; shift to non-fed species.   |

|   |   |  |  |
|---|---|--|--|
| Capture-based aquaculture (e.g. bivalves and crustaceans) | - | Shortage of wild seed and spat fall  | R and D in artificial breeding; hatchery production; incentives for more efficient access and use of available seed. |
| Reef fish culture based on wild seed                      | - | Destruction of coral habitats; loss of wild seed fishery of mostly high value reef fish species. | R&D in artificial breeding; hatchery production  |

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#### Drivers: Rising sea levels and floods

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|  |     |   |   |
|--|-----|---|---|
| All systems in coasts, river basins and deltas | +/- | Salinity intrusion                                      | Shift upstream; switch to euryhaline species; however, pond culture of milkfish, seabass or saline tolerant tilapia in brackish water would, for example, have to be completely based on commercial feed as fertilization is ineffective in high salinity water. Research and explore new fertilization methods in saline systems |
|  | +/- | Erosion of topsoil and loss of land                     | Opportunity for alternative system i.e. from crop farming to aquaculture  |
|  | +/- | Destruction of dikes and water channels, pond siltation | Flood control dams; stronger and taller pond dikes, greenbelt establishment or conservation; better risk maps, improved siting, appropriate monitoring and early warning systems.   |
|  | +/- | Habitat changes or loss; less wild seed.                | Switch to inland aquaculture; recirculation aquaculture system; aquaponics.   |

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#### Driver: Marine circulation and temperature changes

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|                                |   |   |   |
|--------------------------------|---|---|---|
| Culture of carnivorous finfish | - | Reduced catch from artisanal fishing of low-value fish for feed; reduced availability of fishmeal and | Switch to commercial feed formulations (pellets); switch to terrestrial-based feeds and other byproducts. |
|--------------------------------|---|---|---|

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|   |                         |   |
|---|-------------------------|---|
|   | fish-oil.               |   |
| Mariculture: fish and mollusc                               | -                       | Increased fish stress due to suboptimal physiological conditions.   |
|   | -                       | Contingency for emergency management, early harvest and/or relocation   |
|   | -                       | Increased fish stress due to suboptimal physiological conditions.   |
|   | -                       | Contingency for emergency management, early harvest and/or relocation.  |
|   | -                       | Increase in harmful algal blooms  |
|   | -                       | Improved monitoring and early warning systems; physical barriers and other mitigation systems on site; Contingency for relocation of growing sites.                   |
|   | -                       | Reduced spatfall.   |
|   | -                       | R and D in artificial breeding; hatchery production; incentives for more efficient access and use of available seed.  |
|   | +                       | Warmer temperature increases spatfall and growth rates, extends latitudinal range for farming.  |
|   | +                       | Mollusc farming offers an alternative to fish culture   |
| <b>Driver: Acidification</b>                                |                         |   |
| Most shelled molluscs, including species that produce pearl |                         | Adverse effect on shell formation and deposition, probably on pearl development, too  |
|   |                         | Move—if at all possible—to other production zones; switch to freshwater aquaculture; For pearls: culture in deeper waters, new sites; R&D for low pH tolerant strains |
| Seaweed   |                         | Exploratory study shows macro-algae may tolerate long-term elevations in CO <sub>2</sub> levels but macroalgal habitats are altered significantly as pH drops.        |
| Finfish   |                         | Not well understood but could affect larval development   |
| <b>Driver: Water stress from prolonged, intense drought</b> |                         |   |
| Pond culture  | Limits to water supply. | Conservation; efficient allocation and use of water; recirculation aquaculture systems, integration aquaculture-agriculture (e.g.                                     |

|  |   |  |  |
|--|---|--|--|
|  |   |  | aquaponics).   |
| Culture-based fisheries  | - | Water level drops very low in lakes, reservoirs, oxbow lakes, rivers   | Risk mapping to choose more suitable waterbodies; faster growing species; more efficient water-sharing with other users                          |
|  | - | Decreased availability of wild seed  | Artificial breeding; hatchery produced seed.   |
| Cage culture   |   | Eutrophication and upwelling; algal bloom.   | Appropriate monitoring of environmental variables and early warning, insurance, relocation   |
|  |   | Shorter water retention period of lakes, reservoirs, oxbow lakes, rivers.  | Faster growing species; more efficient water sharing with other users.   |
| <b>Drivers: Extreme events: tropical cyclones, heavy and prolonged rainfall causing floods</b> |   |  |  |
| All systems but especially coastal aquaculture   |   | Destruction of structures, facilities; loss of stock; escape of cultured fish; Floods and the heavy run-off of freshwater into coastal aquaculture site especially those for seaweed lowers salinity and stimulate growth of epiphytes that suffocate the seaweed. | Stronger structures; early warning systems; recirculation aquaculture system; aquaponics; greenbelt conservation; coastal embankment; insurance. |



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### Introduction

R is a statistical computing environment having facilities for data manipulation, calculation, graphical display etc. R is also a free implementation of S language, which was developed for statistical computing and by John Chambers of Bell Labs. A commercial version of S is also available as S+® from Insightful Co. R was developed initially by Ross Ihaka and Robert Gentleman. R is developed as open source software and available free for use.

R has an effective data handling and storage facility, a suite of operators for calculations on arrays, in particular matrices; a large, coherent, integrated collection of intermediate tools for data analysis; graphical facilities for data analysis and display.

RStudio is an integrated development environment (IDE) for R. It includes a console, syntax-highlighting editor that supports direct code execution, as well as tools for plotting, history, debugging and workspace management. RStudio is available in open source and commercial editions and runs on the desktop (Windows, Mac, and Linux) or in a browser connected to RStudio Server or RStudio Server Pro (Debian/Ubuntu, RedHat/CentOS, and SUSE Linux).

### Getting R and Rstudio

The Comprehensive R Archive Network (CRAN) is a network of ftp and web servers around the world that store identical, up-to-date, versions of code and documentation for R. R can be downloaded from <https://cran.r-project.org/> . Various versions of R suited to Linux, Mac and Windows are available.

RStudio provides popular open source and enterprise-ready professional software for the R statistical computing environment. RStudio can be downloaded from <https://www.rstudio.com/products/rstudio/download/>

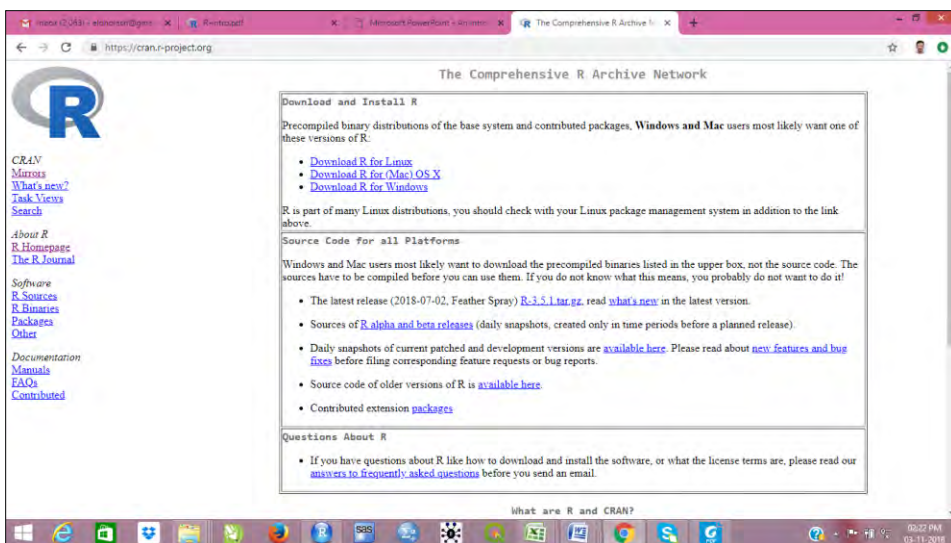


Figure 1: Home page: CRAN

To install R/Rstudio in a given machine, first double-click the downloaded file R.exe/RStudio.exe, then select language as 'English'. R setup wizard window will appear. Select on 'Next' and accept most of the default settings during the installation.

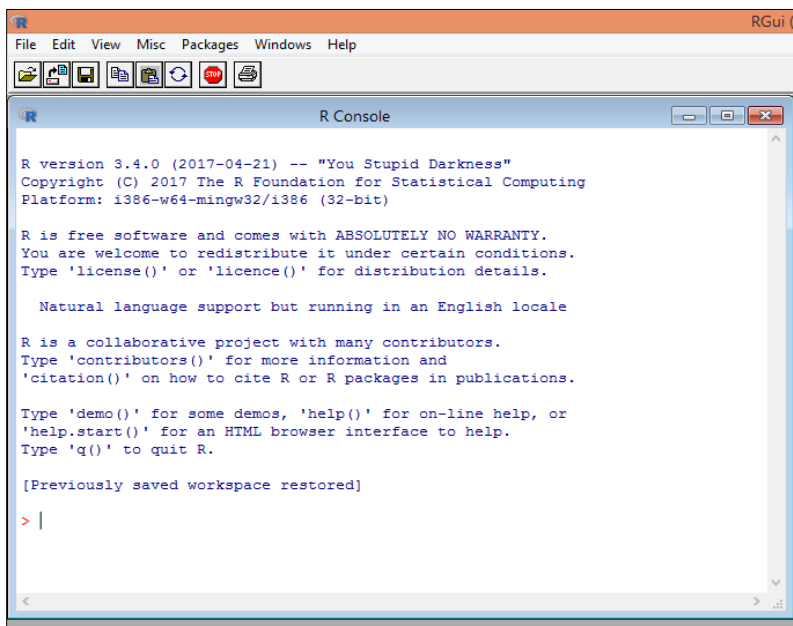


Figure 2.: R console

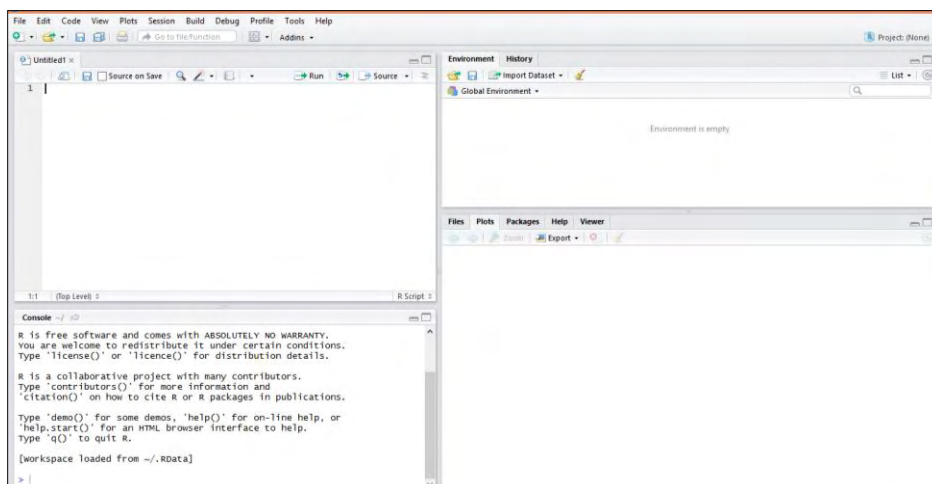


Figure 3: RStudio

R Studio provides more user friendly interface to use R. For using RStudio in machine, base R must be installed in that machine. The interface of RStudio is given in Figure 3. The top left window in Figure 3 has the editor for writing R codes. Bottom left window is similar to R console where R codes get executed. Top right window of RStudio has two tabs: Environments and History, respectively.

### R commands and Case-sensitivity

Technically R is an expression language with a very simple syntax. It is case sensitive as are most UNIX based packages, so ABC, ABc, Abc, abc, aBC, AbC etc. are different symbols and would refer to different variables.

The set of symbols which can be used in R names depends on the operating system and country within which R is being run (technically on the locale in use). Normally all alphanumeric symbols are allowed (and in some countries this includes accented letters) plus '.' and '\_', with the restriction that a name must start with '.' or a letter, and if it starts with '.' the second character must not be a digit. Names are effectively unlimited in length. Elementary commands consist of either expressions or assignments. If an expression is given as a command, it is evaluated, printed (unless specifically made invisible), and the value is lost. An assignment also evaluates an expression and passes the value to a variable but the result is not automatically printed.

In the Environment tab, we can see which objects are currently loaded in R. The History tab gives the history of commands already executed. Bottom right window of RStudio has several tabs namely Files, Plots, Packages, Help and Viewer. The Files tab can be used to explore different files, Plots tab is used to view plots produced from R codes, Packages tab shows the packages already installed and also allows easy installation and loading of packages in a session. Help tab can be used to see the help on R functions and Viewer tab can be used to see local web content.

### **R-help**

To get more information on any specific named function, for example solve, the command is

```
help(solve)
```

An alternative is

```
?solve
```

For a feature specified by special characters, the argument must be enclosed in double or single quotes, making it a “character string”: This is also necessary for a few words with syntactic meaning including if, for and function.

```
help("[")
```

Either form of quote mark may be used to escape the other, as in the string "It's important". Our convention is to use double quote marks for preference. On most R installations help is available in HTML format by running

```
help.start()
```

### **Setting a working directory**

The working directory refers to the directory or folder where R is currently working. By default the working directory is My documents or Documents. One can get the working directory by using code

```
getwd()
```

```
[1] "C:/Users/HP/Documents"
```

R can read and open files from working directory directly without specifying any path. Similarly, it can save files and write to files in the working directory directly. One can reset the working directory to a different folder using the code below.

```
setwd("H:/CMFRI/Lectures delivered/Winter school_Dr.  
Zacharia_2018")
```

```
> getwd()
[1] "C:/Users/HP/Documents"
> setwd("H:/CMFRI/Lectures delivered/winter school_Dr. Zacharia_2018")
> getwd()
[1] "H:/CMFRI/Lectures delivered/winter school_Dr. Zacharia_2018"
> |
```

In the beginning of an R session, it is better to set the working directory to a folder where most of the data files and codes are located.

## Data Types

R is an object oriented language and therefore, all data types in R are some kind of object. Objects may be variables, vectors, matrices, arrays, character strings, functions, or more general structures built from such components. During an R session, objects are created and stored by name. One can use the command `objects()` to display the names of the objects which are currently stored within R.

The collection of objects currently stored is called the workspace. One can remove objects using the function `rm()`. For example, the following code removes objects `x` and `y` from the workspace.

```
rm(x, y)
```

```
> objects()
[1] "Fish_Landings" "fishData"      "mydata"        "PellaTomlinson"
[5] "Scheafer"      "y"             "Year"
> rm(PellaTomlinson)
> objects()
[1] "Fish_Landings" "fishData"      "mydata"        "Scheafer"
[5] "y"             "Year"
> |
```

An object created during an R session can be saved in a file for use in future R sessions. The entire workspace of an R session and the history of all the commands used during the session can also be saved. Some commonly encountered objects are discussed below.

(i) Vectors: Simplest object in R is a vector.

A vector is a collection of elements. For example,

```
Year<-c(1991,1992,1993,1994,1995,1996,1997,1998,1999,2000)
```

creates a vector of 10 numbers. Here the object `Year` contains those numbers and the function `c()` is used to assign those numbers to the object `Year`.

Vectors can be of three types a) numeric b) character and c) logical.

A numeric vector contains numbers, a character vector contains characters and a logical vector can contain values TRUE, FALSE or NA.

(ii) Matrices: A matrix object also is a collection of elements but it has two dimensions. They

can also be numeric, character or logical in nature.

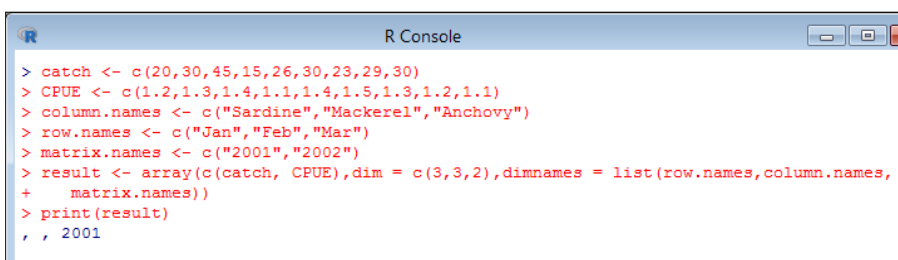
Following is an example of creating a matrix.

```
fish<-matrix(c("sardine","mackerel","tuna","shark"),nrow=2)
fish
```

```
> fish<-matrix(c("sardine","mackerel","tuna","shark"),nrow=2)
> fish
      [,1]      [,2]
[1,] "sardine" "tuna"
[2,] "mackerel" "shark"
> |
```

(iii) Arrays: Arrays are multi-dimensional generalization of vectors and matrices. A two-dimensional array is a matrix. Arrays can have more than two dimensions.

```
catch <- c(20,30,45,15,26,30,23,29,30)
CPUE <- c(1.2,1.3,1.4,1.1,1.4,1.5,1.3,1.2,1.1)
column.names <- c("Sardine","Mackerel","Anchovy")
row.names <- c("Jan","Feb","Mar")
matrix.names <- c("2001","2002")
result <- array(c(catch, CPUE),dim = c(3,3,2),dimnames =
list(row.names,column.names, matrix.names))
print(result)
```



```
R Console
> catch <- c(20,30,45,15,26,30,23,29,30)
> CPUE <- c(1.2,1.3,1.4,1.1,1.4,1.5,1.3,1.2,1.1)
> column.names <- c("Sardine","Mackerel","Anchovy")
> row.names <- c("Jan","Feb","Mar")
> matrix.names <- c("2001","2002")
> result <- array(c(catch, CPUE),dim = c(3,3,2),dimnames = list(row.names,column.names,
+ matrix.names))
> print(result)
, , 2001
```

```

      Sardine Mackerel Anchovy
Jan      20       15       23
Feb      30       26       29
Mar      45       30       30

, , 2002

      Sardine Mackerel Anchovy
Jan      1.2       1.1       1.3
Feb      1.3       1.4       1.2
Mar      1.4       1.5       1.1

> |

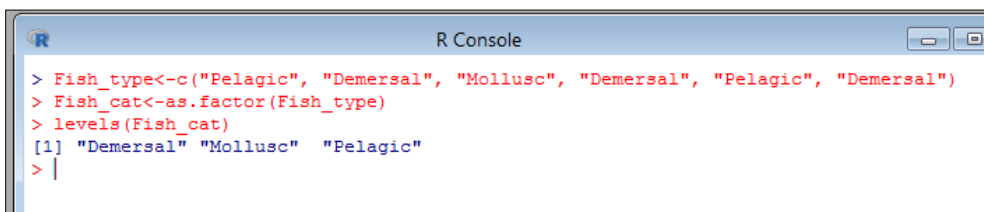
```

(iv) Factors: Factor objects are used to specify categorical or classificatory or grouping variables. For example, males and females are two levels of a variable gender. Then gender can be thought of a factor object.

```

Fish_type<-c("Pelagic", "Demersal", "Mollusc", "Demersal",
"Pelagic", "Demersal")
Fish_cat<-as.factor(Fish_type)
levels(Fish_cat)

```



```

R Console
> Fish_type<-c("Pelagic", "Demersal", "Mollusc", "Demersal", "Pelagic", "Demersal")
> Fish_cat<-as.factor(Fish_type)
> levels(Fish_cat)
[1] "Demersal" "Mollusc"  "Pelagic"
> |

```

Factor variables are particularly useful in analysis of variance and in linear model with grouping variables.

v) Data frames: A data frame is a two dimensional object. But unlike matrices, different columns of data frame can be different types, for example some columns can be numeric, some columns can be character, some columns can be factors. Here a column generally refers to a variable.

```

Landings<-c(25,29,37,50)
Type_fish<-c("sardine","mackerel","shrimp","prawn")
FishData<-data.frame(Type_fish, Landings)
FishData

```

```

R Console
> Landings<-c(25,29,37,50)
> Type_fish=c("sardine","mackerel","shrimp","prawn")
> FishData=data.frame(Type_fish, Landings)
> FishData
  Type_fish Landings
1  sardine      25
2 mackerel      29
3  shrimp      37
4  prawn       50
> |

```

The `data.frame()` function is used to create a data frame.

vi) Lists: A list is a collection of objects where each object can be of different type. For example, a list can have first object as a vector, second object as a matrix and third object as a data frame.

```

Year<-c(1991,1992,1993,1994,1995,1996,1997,1998,1999,2000)
fish<-matrix(c("sardine","mackerel","tuna","shark"),nrow=2)
Landings<-c(25,29,37,50)
Type_fish<-c("sardine","mackerel","shrimp","prawn")
FishData<-data.frame(Type_fish, Landings)
Mylist=list(Year, fish, FishData)
Mylist

```

```

> Year<-c(1991,1992,1993,1994,1995,1996,1997,1998,1999,2000)
> fish<-matrix(c("sardine","mackerel","tuna","shark"),nrow=2)
> Landings<-c(25,29,37,50)
> Type_fish<-c("sardine","mackerel","shrimp","prawn")
> FishData<-data.frame(Type_fish, Landings)
> Mylist=list(Year, fish, FishData)
> Mylist

[[1]]
[1] 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

[[2]]
  [,1] [,2]
[1,] "sardine" "tuna"
[2,] "mackerel" "shark"

[[3]]
  Type_fish Landings
1  sardine      25
2 mackerel      29
3  shrimp      37
4  prawn       50
> |

```

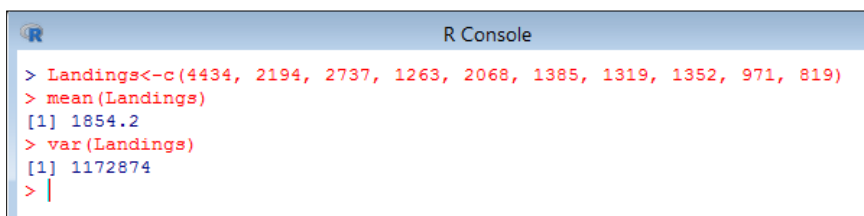


## R Functions

Functions in R are a kind of objects which takes one or more inputs and produces some result(s) as output. R has a number of in-built functions. R also provides facility to create new functions by users. R has huge number of in-built functions.

As an example, to obtain the mean and variance of landings of sharks during the period 2007-2016: 4434, 2194, 2737, 1263, 2068, 1385, 1319, 1352, 971, 819, the following code can be used.

```
Landings<-c(4434, 2194, 2737, 1263, 2068, 1385, 1319, 1352,
971, 819)
mean(Landings)
var(Landings)
```

A screenshot of the R Console window. The title bar says "R Console". The console shows the following text: a prompt ">" followed by "Landings<-c(4434, 2194, 2737, 1263, 2068, 1385, 1319, 1352, 971, 819)" in red; a prompt ">" followed by "mean(Landings)" in red; the output "[1] 1854.2" in blue; a prompt ">" followed by "var(Landings)" in red; the output "[1] 1172874" in blue; and a final prompt ">" followed by a vertical bar "|" in red.

```
> Landings<-c(4434, 2194, 2737, 1263, 2068, 1385, 1319, 1352, 971, 819)
> mean(Landings)
[1] 1854.2
> var(Landings)
[1] 1172874
> |
```

Here, `c()`, `mean()` and `var()` are in-built functions of R. The function `c()` assigns those numbers to the object `Landings`. The commands `mean(Landings)` and `var(Landings)` computes the mean and variance of an object `Landings`. Here, `Landings` is the input, also called argument, to the function `mean()` and `var()`.

A complete list of in-built functions is available in the document R reference manual. The R reference manual opens by clicking on Help Manuals (in PDF) R reference. It opens the full reference manual. It contains a complete list of all the functions and objects in base R. Apart from in-built functions, a large number external functions are available in contributed packages. Contributed packages are nothing but a collection of functions written by the authors of the packages to perform specific analysis. The manual of a package contains the details of the functions provided in that package. To know what are the argument(s) of a function and how to use it, you can use the code `help(functionname)` where `functionname` is the name of the function. This opens an html page in browser containing the details of the function. For example, `help(aov)` gives the details of the usage of the function `aov()`.

Some of the statistical functions are as follows:

- `mean(x)`: Mean of the numbers in vector x
- `median(x)`: Median of the numbers in vector x
- `var(x)`: Estimated variance of the population from which the numbers in vector x are sampled
- `sd(x)`: Estimated standard deviation of the population from which the numbers in vector x are sampled
- `sort(x)`: The numbers in vector x in increasing order
- `rank(x)`: Ranks of the numbers (in increasing order) in vector x
- `rank(-x)`: Ranks of the numbers (in decreasing order) in vector x
- `t.test(x,mu=n, alternative = "two.sided")`: Two-tailed t-test that the mean of the numbers in vector x is different from n.
- `t.test(x,mu=n, alternative = "greater")`: One-tailed t-test that the mean of the numbers in vector x is greater than n.
- `t.test(x,mu=n, alternative = "less")`: One-tailed t-test that the mean of the numbers in vector x is less than n.
- `t.test(x,y,mu=0, var.equal = TRUE, alternative = "two.sided")`: Two-tailed t-test that the mean of the numbers in vector x is different from the mean of the numbers in vector y. The variances in the two vectors are assumed to be equal.
- `t.test(x,y,mu=0, alternative = "two.sided", paired = TRUE)`: Two-tailed t-test that the mean of the numbers in vector x is different from the mean of the numbers in vector y. The vectors represent matched samples.
- `cor(x,y)`: Correlation coefficient between the numbers in vector x and the numbers in vector y
- `cor.test(x,y)`: Correlation coefficient between the numbers in vector x and the numbers in vector y, along with a t-test of the significance of the correlation coefficient.
- `lm(y~x, data = d)`: Linear regression analysis with the numbers in vector y as the dependent variable and the numbers in vector x as the independent variable. Data are in data frame d.
- `coefficients(a)`: Slope and intercept of linear regression model a.
- `confint(a)`: Confidence intervals of the slope and intercept of linear regression model a

## R packages

All R functions and datasets are stored in packages. Only when a package is loaded are its contents available. This is done both for efficiency (the full list would take more memory and would take longer to search than a subset), and to aid package developers, who are protected from name clashes with other code.

To see which packages are installed at your site, issue the command `library()` with no arguments.

To load a particular package named say, “boot”, use a command like `library(boot)`.

Users connected to the Internet can use the `install.packages()` and `update.packages()` functions (available through the Packages menu in the Windows and MacOS GUIs, see Section “Installing packages” in R Installation and Administration) to install and update packages.

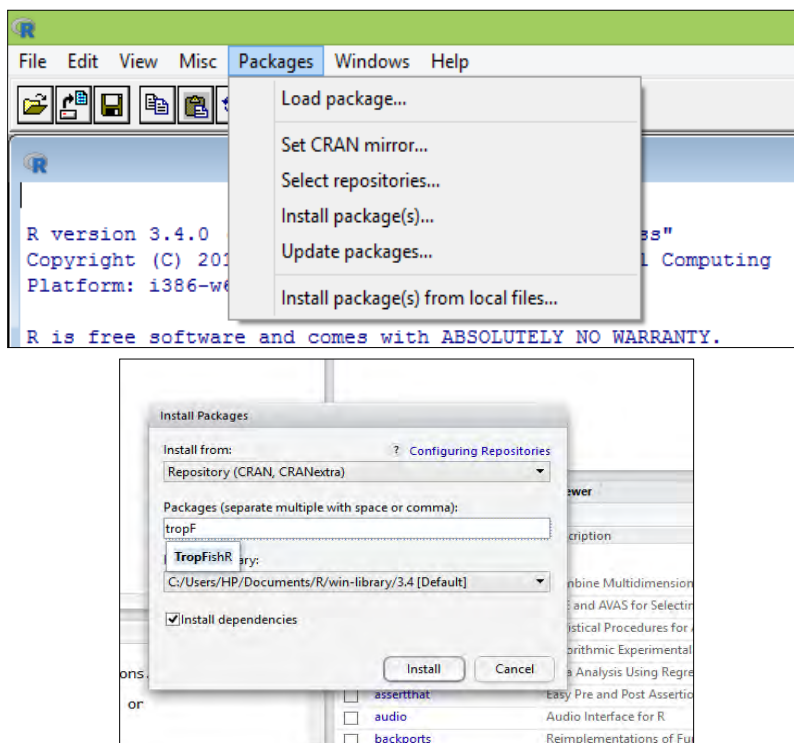


Figure 4: Package installation in R and Package installation in RStudio

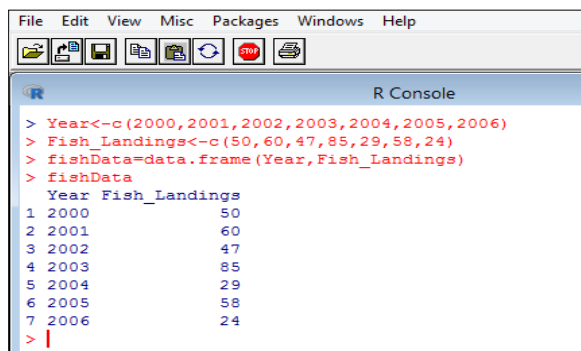
To see which packages are currently loaded, use `search()`.

## Reading Data File

(i) Entering data in R directly:

Suppose a data set contains few variables and few observations, then it can be read in R by typing in the Console as shown in the following example.

```
Year<-c(2000,2001,2002,2003,2004,2005,2006)
Fish_Landings<-c(50,60,47,85,29,58,24)
fishData=data.frame(Year,Fish_Landings)
fishData
```



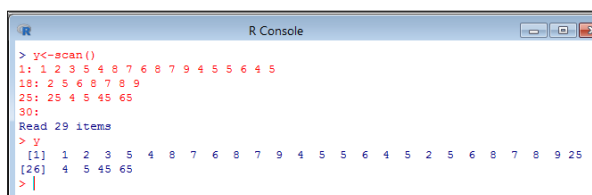
```
R Console
> Year<-c(2000,2001,2002,2003,2004,2005,2006)
> Fish_Landings<-c(50,60,47,85,29,58,24)
> fishData=data.frame(Year,Fish_Landings)
> fishData
  Year Fish_Landings
1 2000             50
2 2001             60
3 2002             47
4 2003             85
5 2004             29
6 2005             58
7 2006             24
> |
```

Note that `data.frame()` function combines the vectors month and rainfall into a data frame called `fishData`. Note that a dataset in R is always in the form of a two-dimensional array with columns representing variables and rows representing individual observations. Sometimes one may be interested to know the names of variables in a data set loaded in R. For example, to know the names of the variables in data set `fishData`, one can use following command:

```
names(fishData)
```

```
> names(fishData)
[1] "Year"           "Fish_Landings"
```

The `scan()` function can also be used to read data directly typed in R console. For example, `y<-scan()`



```
R Console
> y<-scan()
1: 1 2 3 5 4 8 7 6 8 7 9 4 5 5 6 4 5
18: 2 5 6 8 7 8 9
25: 25 4 5 45 65
30:
Read 29 items
> y
[1] 1 2 3 5 4 8 7 6 8 7 9 4 5 5 6 4 5 2 5 6 8 7 8 9 25
[26] 4 5 45 65
> |
```

When entering data from keyboard using `scan()` function, one has to hit enter button twice to stop scanning. Then R stops scanning and loads the data into the object.

The function `scan()` is also able to read data from external file.

(ii) Loading data in R from an external file:

Most often the data may not be just a few observations. There may be quite many variables and observations. In that case, the data may be in a spreadsheet or some other external file, or from some other statistical software or from some web page. R provides facilities for loading data from each of them.

(a) Reading data from text file:

Data in text file should be kept such that the individual observations are separated with a delimiter. Some commonly used delimiters are `' ',';','t',' '` i.e., blank space, `' '`, `'@'`, `'&'`, `'*'` etc. But be sure that none of the observations or variables in the data set have any of those characters, otherwise data will be loaded improperly and there may be error in loading of data.

Consider a text file contains landings of a particular species in the month of January and July during 2000-20005 with comma(',') as a delimiter.

Year,Month,Catch

2000,jan,52

2000,jul,40

2001,jan,53

2001,jul,54

2002,jan,42

2002,jul,48

2003,jan,35

2003,jul,39

2004,jan,60

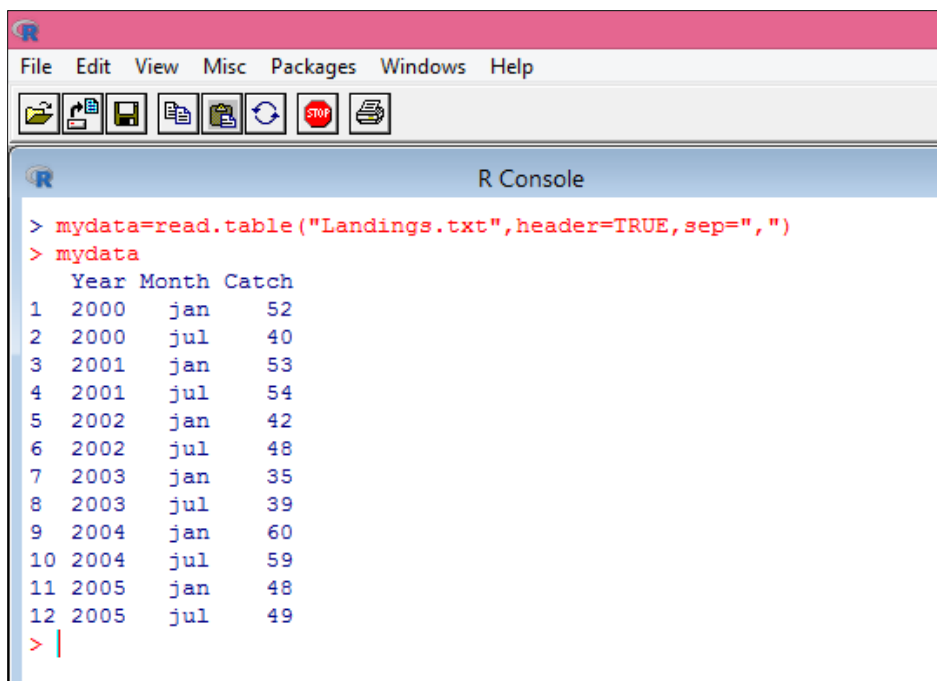
2004,jul,59

2005,jan,48

2005,jul,49

Let the file name is Landings.txt and is kept in the working directory. This data can be loaded in R by using the function `read.table()` as follows:

```
mydata=read.table("Landings.txt",header=TRUE,sep=",")
mydata
```



```
> mydata=read.table("Landings.txt",header=TRUE,sep=",")
> mydata
  Year Month Catch
1  2000   jan    52
2  2000   jul    40
3  2001   jan    53
4  2001   jul    54
5  2002   jan    42
6  2002   jul    48
7  2003   jan    35
8  2003   jul    39
9  2004   jan    60
10 2004   jul    59
11 2005   jan    48
12 2005   jul    49
> |
```

The first argument of `read.table()` refers to the external file. The second argument `header=TRUE` tells R that there is header in the rainfall.txt file, and those are used as variable names for the data. If there is no header in a text file, then `header=FALSE` should be used. Third argument `sep=","` tells R that observations are separated by a ','. There are other arguments to `read.table()` function, but these three are essential. The details of the usage of the function `read.table()` is available with `help(read.table)` in the Console.

(b) Loading data from a spreadsheet:

There are some other functions to read files with specific delimiters. The function `read.csv()` function loads comma separated value (csv) files, i.e., files with comma delimited observations, `read.csv2()` function loads data from semicolon (;) delimited files, `read.delim()` and `read.delim2()` functions load data from tab delimited files.

(c) Loading data from a spreadsheet:

To load data from an excel file to R, the relevant worksheet may be saved into a tab delimited text file or into a csv file and then the text file or .csv may be loaded using `read.table()` or `read.csv()` function. However, if to read the data

from excel directly into R, a package called `xlsx` is needed. An example of loading data from excel is shown below.

```
library(xlsx)
read.xlsx("myfile.xlsx", sheetName = "Sheet1")
```

(c) Reading data from a webpage:

Suppose some data is available on a webpage. To read a dataset from a webpage the function `read.table()` can be used with the complete address of the page. For example,

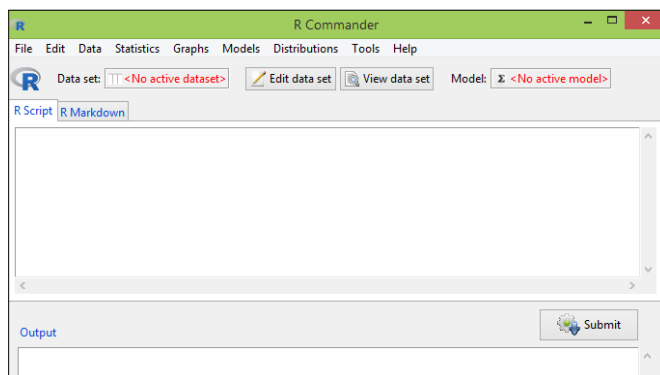
```
webdata=read.table("http://cmfri.org.in/datasets/
effort.dat")
```

### R Commander: A graphical interface for R

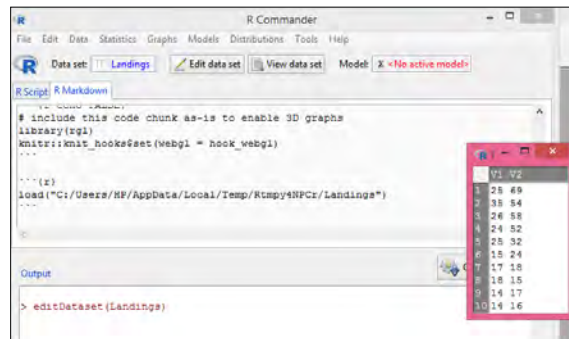
R provides a powerful and comprehensive system for analysing data and when used in conjunction with the R-commander (a graphical user interface, commonly known as Rcmdr) it also provides one that is easy and intuitive to use. Basically, R provides the engine that carries out the analyses and Rcmdr provides a convenient way for users to input commands. The Rcmdr program enables analysts to access a selection of commonly-used R commands using a simple interface that should be familiar to most computer users. It also serves the important role of helping users to implement R commands and develop their knowledge and expertise in using the command line - an important skill for those wishing to exploit the full power of the program (<http://www.rcommander.com/>).

Loading R commander:

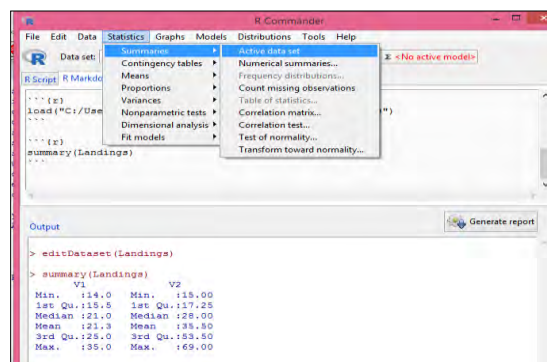
```
install.packages(Rcmdr)
library(Rcmdr)
```



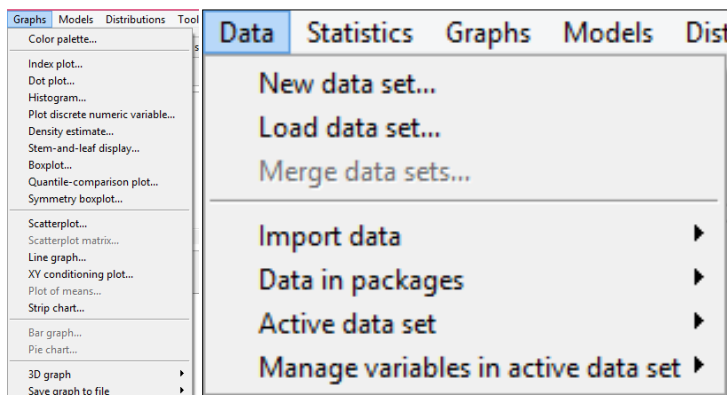
Active data set:



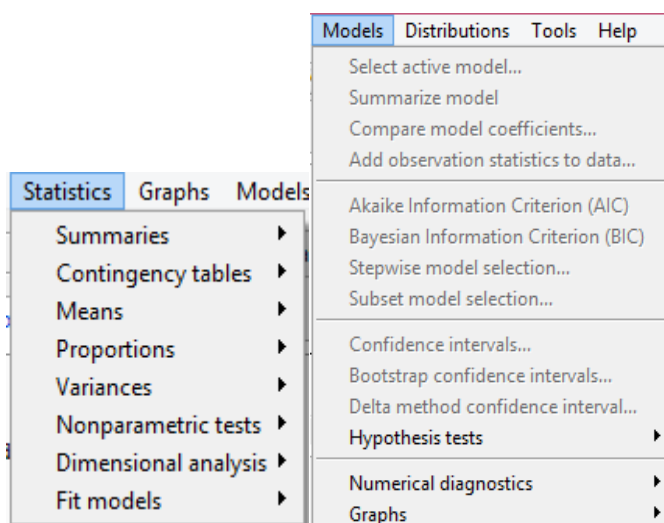
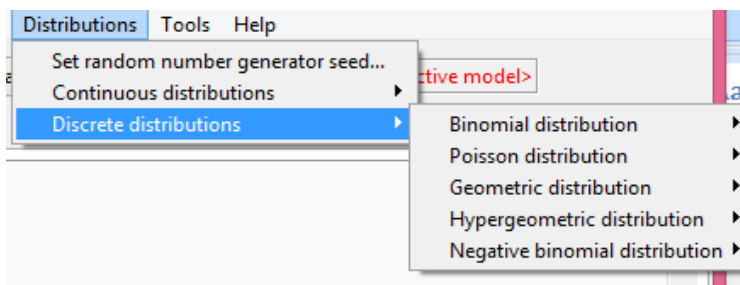
Summary of the active data set:



Menu options







### Some examples

The following data (Landings of Bombay duck, Crabs, Indian mackerel, Ribbon fishes and Sharks during 1997-2017 along A.P. coastline) is used for illustrations:

| Year | Bombay duck | Crabs | Indian mackerel | Ribbon fishes | Sharks |
|------|-------------|-------|-----------------|---------------|--------|
| 1997 | 951         | 3491  | 15767           | 11273         | 3561   |
| 1998 | 732         | 3326  | 14879           | 8471          | 2956   |
| 1999 | 1032        | 3014  | 19681           | 20170         | 6871   |
| 2000 | 693         | 2791  | 9834            | 13842         | 4914   |
| 2001 | 2165        | 2929  | 9306            | 7278          | 3257   |
| 2002 | 1754        | 4955  | 14206           | 18372         | 1613   |
| 2003 | 701         | 5113  | 22572           | 15565         | 1921   |

|      |      |      |       |       |      |
|------|------|------|-------|-------|------|
| 2004 | 2986 | 6877 | 20209 | 9995  | 2250 |
| 2005 | 1318 | 5405 | 17665 | 6398  | 1855 |
| 2006 | 1821 | 6804 | 13004 | 16522 | 3806 |
| 2007 | 1832 | 5324 | 7903  | 11449 | 4434 |
| 2008 | 688  | 4678 | 18127 | 15960 | 2194 |
| 2009 | 556  | 6757 | 23078 | 11895 | 2737 |
| 2010 | 1053 | 6298 | 19564 | 9363  | 1263 |
| 2011 | 1262 | 5718 | 22410 | 15348 | 2068 |
| 2012 | 1057 | 7041 | 28407 | 21777 | 1385 |
| 2013 | 1335 | 5008 | 33716 | 18800 | 1319 |
| 2014 | 930  | 7007 | 55631 | 20269 | 1352 |
| 2015 | 443  | 5543 | 28236 | 8808  | 971  |
| 2016 | 466  | 4571 | 22849 | 14993 | 819  |

To read the file:

```
Landings=read.csv("LandingsData.csv",header=TRUE,sep=",")
```

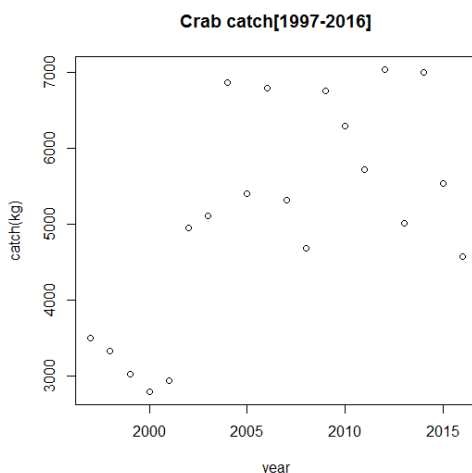
To get a summary:

```
> summary(Landings)
      Year      BombayDuck      Crabs      IndianMackerel      Ribbon_Fishes
Min.   :1997   Min.   : 443   Min.   :2791   Min.   : 7903   Min.   : 6398
1st Qu.:2002   1st Qu.: 699   1st Qu.:4301   1st Qu.:14711   1st Qu.: 9837
Median :2006   Median :1042   Median :5218   Median :19623   Median :14418
Mean    :2006   Mean    :1189   Mean    :5132   Mean    :20852   Mean    :13827
3rd Qu.:2011   3rd Qu.:1440   3rd Qu.:6413   3rd Qu.:22906   3rd Qu.:16985
Max.    :2016   Max.    :2986   Max.    :7041   Max.    :55631   Max.    :21777
```

```
Sharks
Min.   : 819
1st Qu.:1377
Median :2131
Mean    :2577
3rd Qu.:3333
Max.    :6871
> |
```

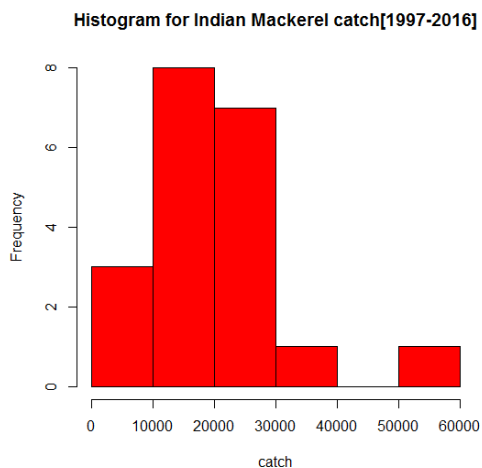
To make plot the landings:

```
plot(Landings$Year, Landings$Crabs, main="Crabcatch[1997-2016]", xlab="year", ylab="catch(kg)" )
```



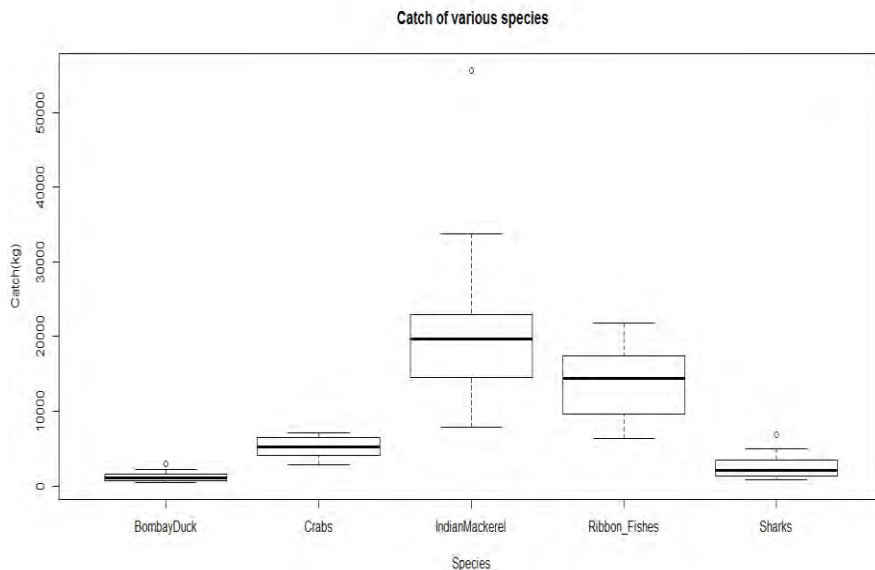
To make a histogram:

```
hist(Landings$ IndianMackerel, main="Histogram for Indian Mackerel catch[1997-2016]", xlab="catch", col="red", breaks=5)
```



To make a Box plot:

```
boxplot(Landings[,-1], main=" Catch of various species",
xlab="Species", ylab="Catch(kg) ")
```



To make a Stem and leaf plot:

```
> stem(Landings$Shark)
```

The decimal point is 3 digit(s) to the right of the |

```
0 | 803344699
2 | 12370368
4 | 49
6 | 9
```

```
> stem(Landings$Sharks,scale=2)
```

The decimal point is 3 digit(s) to the right of the |

```
0 | 8
1 | 03344699
2 | 1237
3 | 0368
4 | 49
5 |
6 | 9
```

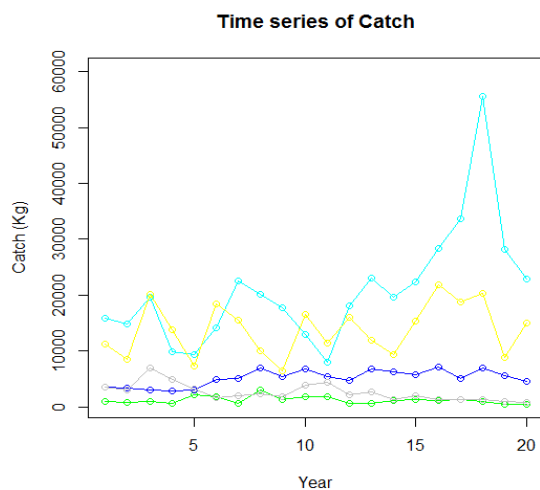
```
> stem(Landings$Sharks,scale=3)

The decimal point is 3 digit(s) to the right of the |

0 | 8
1 | 03344
1 | 699
2 | 123
2 | 7
3 | 03
3 | 68
4 | 4
4 | 9
5 |
5 |
6 |
6 | 9
```

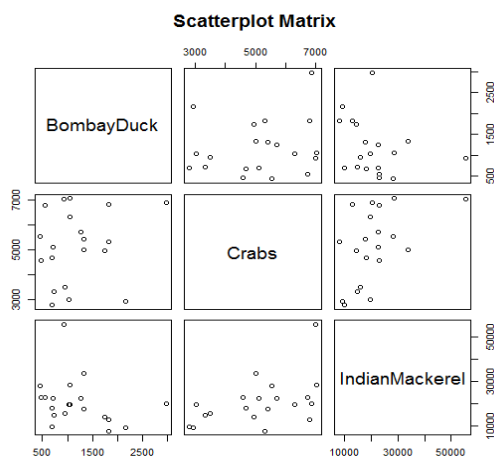
To make plot of all the species landings together:

```
plot(Landings$ IndianMackerel, type = "o",col = "cyan",
xlab = "Year", ylab = "Catch (Kg)", main = "Time series of
Catch", ylim=c(500, 60000)) # type 'o' means both point and
lines
lines(Landings$Crabs, type = "o", col = "blue")
lines(Landings$BombayDuck, type = "o", col = "green")
lines(Landings$Ribbon_Fishes, type = "o", col = "yellow")
lines(Landings$Sharks, type = "o", col = "grey")
```



To prepare a scatter plot matrix

```
pairs (~BombayDuck+Crabs+IndianMackerel, data=Landings,
main=" Scatterplot Matrix")
```



To study length-weight relationship:

```
len<-c(90, 128, 112, 68, 56, 58, 111, 111, 115, 65)
wt<-c(9.3, 32.5, 19, 4.4, 2.1, 2.8, 16.1, 17.9, 22.7, 3.4)
logL<-log(len)
logW<-log(wt)
lm1<-lm(logW~logL)
summary(lm1)
```

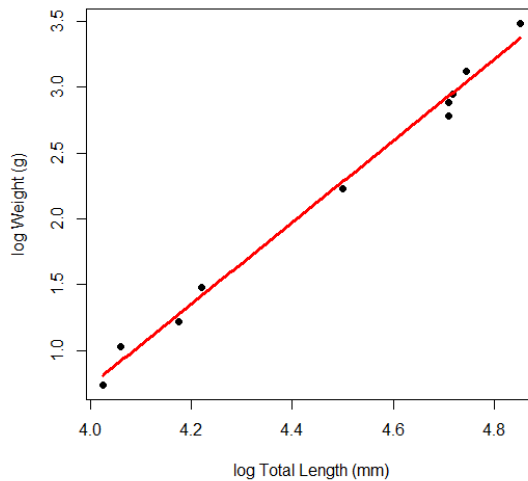
```
Call:
lm(formula = logW ~ logL)

Residuals:
    Min       1Q   Median       3Q      Max
-0.14942 -0.04967 -0.02749  0.08066  0.11233

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -11.6354     0.4401  -26.44 4.50e-09 ***
logL         3.0924     0.0982   31.49 1.13e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.09391 on 8 degrees of freedom
Multiple R-squared:  0.992,    Adjusted R-squared:  0.991
F-statistic: 991.6 on 1 and 8 DF, p-value: 1.125e-09
```

```
library(FSA)
fitPlot(lm1,xlab="log Total Length (mm)",ylab="log Weight (g)",main="")
```



To test  $H_0 : \beta = 3 \Rightarrow H_0 : \text{"Isometric growth"}$   $H_A : \beta \neq 3 \Rightarrow H_A : \text{"Allometric growth"}$ :

```
> hoCoef(lm1,2,3)
term Ho Value Estimate Std. Error      T df   p value
  2      3 3.092374 0.09820357 0.9406334  8 0.3744233
```

# '2' means second coefficient and '3' means the value of  $H_0$

## References

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- [http://www.iasri.res.in/sscnars/sas\\_manual/19-An%20Introduction%20to%20R.pdf](http://www.iasri.res.in/sscnars/sas_manual/19-An%20Introduction%20to%20R.pdf)
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### Introduction

Disasters due to extreme weather events are a cause of concern across the globe. Between 1998 and 2017 climate-related and geophysical disasters killed 1.3 million people and left nearly 4.4 billion injured, homeless and displaced. The direct economic losses by all the disasters across the globe are valued at US\$ 2,908 billion. The economic loss due to climate-related disasters alone accounted US\$ 2,245 billion (77% of the aggregate loss) (UNISDR, 2018). Ninety one percent of all the disasters were caused by floods, storms, droughts, heat waves and other extreme weather events.

India is extremely vulnerable to climate change impacts because of its wide geographical and demographic variations. Extreme weather events had caused catastrophic disasters across the country in recent years. According to a recent study by the Indian Institute of Tropical Meteorology, Pune, the intensity and frequency of extreme rainfall events had increased in India in the last few decades and south and central India are predicted as more sensitive to warming than north India, with more rainfall extremes in response to climate warming. (Mukherjee et al, 2018). According to the National Disaster Management Authority (NDMA), over 40 million hectares or 12% of the country's land is prone to floods and river erosion. The past decade the country witnessed several geophysical and climate change induced disasters (<https://ndma.gov.in>). The floods in Jhelum and Chenab in Kashmir in 2014, Cyclone Ockhi in 2017 and Kerala floods in 2018 are to name a few catastrophic disasters in the country. These disasters caused severe damage to the lives and livelihoods of the population apart from the huge economic losses.

### **Extreme events due to Climate change**

Change in climate due to increased greenhouse gas emissions and aerosols in the atmosphere resulted in extreme weather events in most part of the world. Singha and Patwardhana (2012) in their study on the spatio temporal distribution of extreme events in India classified 10 key extreme events such as flood, tropical cyclone, heat wave, cold wave also gale, squall, lightning, dust-storm, hailstorm and thunderstorm. Analysis of long-term temperature and precipitation records has revealed changes in the mean climatic state with increase in atmospheric carbon dioxide (CO<sub>2</sub>) levels which affect the frequency and intensity of extreme climatic events (Singha and Patwardhana, 2012).

The impact of anthropogenic activities on climate change is clearly evident with rising greenhouse gas emissions and the associated temperature, humidity and sea level rise. The warmer the world, the atmosphere will hold more water and result in intense and extreme rainfall. The heat and humidity also alter winds and circulation of the atmosphere and hence the oceans. This leads to changes in the rates of evaporation and the intensity and frequency of rainfall. (Easterling D.R *et al.* 1997, Easterling D.R *et al.* 2000; Meehl G.A., *et al.* 2000).

### **Economic loss due to extreme events**

The economic loss due to extreme events assumed greater significance with the increase in the frequency of events across the Globe. UNFCC (2012) defines losses and damages due to climate change impacts as 'the actual and/or potential manifestation of impacts associated with climate change in developing countries that negatively affect human and natural systems'. The 'loss' consist of negative impacts in which restoration is impossible, and 'damage consist of negative impacts in which restoration is possible. The post disaster economic loss assessment is imperative for designing recovery and reconstruction strategies. Standard methodologies for assessment of economic loss have been developed by several international agencies following catastrophic disasters in several locations. **The Damage loss and needs assessments methodology (DaLA)** developed by the Economic Commission for Latin America and the Caribbean (ECLAC) in the 1970s has been recognized as a globally applied tool to quantify the impacts of disasters and to determine the financial resources to achieve the reconstruction and recovery. It is a flexible tool that can be adapted to specific disaster types and government ownership requirements. The DaLA Methodology uses the national accounts and statistics of the country government as baseline data to assess damage and loss. It also assesses the

impacts of disasters on individual livelihoods and incomes to estimate the needs for recovery and reconstruction.

The economic loss due to some of the recent extreme events are presented in Table 1. Among the catastrophic disasters due to extreme climatic events in the past 15 years, the Kerala floods in 2018 reported to cause the highest economic loss (Rs.25000 crores based on world bank report) followed by the Maharashtra floods in 2005 (Rs.5000 crores).

Table 1. Economic loss due to extreme events in India in the recent years

| Event                    | Period         |  | Affected locations   | Economic loss  |
|--------------------------|----------------|--|--|--|
| Maharashtra floods       | July 2005      | 994mm rainfall in 24 hours                   | Mumabi, Raigad, Chiplun, Khed, Ratnagiri, Kalyan, Kohlapur, Sagli and, Goa   | Rs.5000crore   |
| Cyclone, Alia            | May, 2009      | 6.1m flood water inundated Sunderbans region | Est Midnapur, Howrah, Hoogly, South 24 Parganas, and Kolkotha in West Bengal | Rs.1500crore   |
| Uttarakhad flash floods  | June, 2013     | 385.1 mm rainfall                            | Uttakhand, Haryana, UP, HP   | Rs.1000 crore  |
| Jammu and Kashmir floods | Sept, 2014     | 585mm rainfall                               | Jammu and Kashmir  | Rs.5700 crores   |
| Cyclone, Okhi, Kerala    | December, 2017 |  | Tamil Nadu, Kerala and the Union Territory of Lakshadweep                    | Rs. 1000 cr (Tamil Nadu)<br>Rs. 1843 cr (Kerala)<br>and Rs. 500 cr (Lakshadweep) |
| Floods, Kerala           | August, 2018   | 700mm rain fall                              | 14 districts of Kerala state   | Rs.25,046 crore  |

Source: [www.downtoearth.org](http://www.downtoearth.org), [www.newindianexpress.org](http://www.newindianexpress.org), [www.timesofindia.com](http://www.timesofindia.com)

### Steps in Damage loss and needs assessments methodology (DaLA)

The following steps are involved in assessing the damages and losses post disaster (Torrente, 2012).

#### *Sector wise baseline data collection*

The sectoral data collection need to be done based on discussions with Govt representatives, private or NGOs before undertaking field visits to the affected areas. This will provide a quantitative base for comparing the effects and impacts of the disaster.

#### *Field visit to the affected areas*

Sample surveys of affected enterprises and industries and other sectors will be conducted for extrapolating the results. Representative areas will be chosen based on discussion with relief personnel, various government and private agencies who had already visited the affected locations.

#### *Extrapolation of results to entire affected area*

The data collected from representative areas will be used to extrapolate the results to the entire affected area

#### *Sector by sector assessment*

The aggregation of damages and losses in each sector will be done for estimating the gross economic loss due the disaster

### **Damages**

The assessment damage loss consist of the following

a.Total or partial destruction of assets, including buildings, infrastructure, stocks, natural resources, etc.

The Damage occurs during or immediately after the disaster will be included under this. Damage is measured in physical terms, and a monetary replacement value is assigned to it. Eg.The value of a totally or partially destroyed equipments/ machinery should be its market value just before it was destroyed and not the cost of a brand new one.

### **Losses**

a. Production not obtained due to the disaster or higher production costs

b.Higher operational costs and lower revenues

c.Unexpected expenditures (humanitarian assistance, demolition and debris removal, relocation of human settlements).They are measured in monetary terms at current prices. The sum of damages and losses are termed as disaster effects.

### **Long term macroeconomic impacts on the local economy due to disasters**

This consists of the impacts on GDP, Prices/inflation, employment, balance of payment, fiscal balance, national debts and repayments. In addition to this the economy will also be affected due to poverty, gender impact and impacts on environment.

### **Post disaster recovery and reconstruction needs**

In DaLA methodology, the value of destroyed physical assets (damage) and resulting changes in economic losses for each sector in the affected area are assessed. For analyzing the disaster impact, the impact of the disaster on the national economy and the expected temporary decline in personal income are

estimated. The cost of reconstruction and recovery are then assessed to know its impact on the economy. Based on the quantitative estimates of the damage and losses, financial needs for the recovery, reconstruction and disaster risk reduction or management are estimated. The value of reconstruction needs will normally higher than the estimated value of damage.

#### *Steps in identifying the recovery and reconstruction needs*

1. Analyzing the impact of disasters based on damages and losses
2. Setting the recovery and reconstruction strategies
3. Identifying post disaster needs

Disaster needs consists of both recovery needs and reconstruction needs

#### *Recovery needs*

The recovery needs in the Agricultural sector designed to mitigate the adverse effects of disasters include subsidies for the purchase of inputs or equipments, supply of production inputs or financial assistance for repair of infrastructure. This can be in terms of purchase of seeds, fingerlings, fertilizers, insecticides, farm implements, and repair of ponds, fish cages or crafts and gears . Farmers also can be supported through production credit and tax exemptions.

#### *Reconstruction needs*

In general the reconstruction needs in the agricultural sector can be categorised under the following activities

- Reconstruction of heavily damages structures such as input or product storage buildings, irrigation facilities, research facilities, hatcheries etc.
- Relocation of important facilities to safer areas
- Replacements of Agricultural equipment's, crafts and gears in fisheries sector
- Research for developing plant, animal or fish varieties with capacity to adapt to disaster prone areas
- Disaster resilient standards for construction
- Disaster preparedness and mitigation projects: Development of climate smart villages

### **Economic impact of extreme events: A case study on damages and losses to cage fish farms during the Kerala floods, 2018**

Kerala once considered a region of low climate vulnerabilities had witnessed serious catastrophic disasters due to extreme events in the recent years. Analysis of loss and damages due to extreme events in Kerala assumed greater

significance with the occurrence of Ockhi in December 2017 and the deluge of August 2018. Tsunami, Ockhi and the floods caused serious damages and economic loss to the agricultural sector and fisheries sector in particular.

During the devastating deluge of August, 2018, the unprecedented rains almost 170% above the normal caused serious destruction to the state in terms of loss of lives damage to infrastructure, electricity, businesses and farming sector (Irudayarajan *et al.*, 2018). The deluge of 2018 said to be the worst in the 100 years caused serious damage to the lives and livelihoods of the population in many parts of the state. A preliminary assessment by the joint team of World Bank and Asian Development Bank has estimated the economic loss due to the catastrophic flood and landslides at Rs.25,046 crore (\$US3.5 billion). The agricultural sector assumed to be one of the worst affected sectors of the state and the estimated cost of recovery from damage to the tune of Rs.2,093 crore (www.weather.com).The Post Disaster Needs Assessment (PDNA) report prepared by the UN assessed the damage and loss due to the floods. It said the state would need about Rs. 31,000 crore for recovery and reconstruction. The highest amount would be needed for reconstruction of roads and transportation (Rs. 10,046 crore), followed by housing (Rs 5,443 crore), agriculture, fisheries and livestock (Rs.4, 498 crore), employment and livelihood (Rs.3, 896 crore), other infrastructure (Rs.2, 446 crore), irrigation (Rs. 1,483 crore) and water and sanitation (Rs.1, 331 crore) (www.timesofindia.com).

The deluge hit the state during August 2018 was a serious setback to the efforts taken by the Central Marine Fisheries Research Institute (CMFRI) along with several other institutional agencies to popularise cage farming activities in the state. Many fish farmers in the coastal districts of the state have already adopted this technology as a source of livelihood owing to its techno-economic feasibility and promotional activities by various institutional agencies. There was a gradual and consistent progress in the cage farming activities in other districts like Thrissur, Kozhikkode, Alappuzha, Malappuram, Kollam and Thiruvananthapuram. The flash floods caused considerable loss of fishes stocked in cages as well damage to cage structure and other related infrastructure.

### **Methodology**

A rapid damage and loss assessment was done immediately after the flood waters had receded in the affected coastal districts of Kerala. The extent of damage and economic loss to cage farms and the need assessments were done based on data collected from fish farmers in the selected districts and data from

state department of fisheries. The deluge affected the cage farmers in terms of loss or damage to cage structures and loss of fishes stocked in the cages. The tangible direct losses to the cage farms alone is included in the analysis and the indirect losses such as loss of income, employment loss and long term macro-economic impact are not covered in the analysis. The direct tangible damage is the most important loss assessed in many of the previous studies on economic loss due to disasters (Hammond *et al.*, 2015). The economic loss to cage farms was assessed in terms of foregone value of output due to loss of fishes stocked in cages and damages in terms of input loss and infrastructure loss.

#### *Damage*

The economic loss was estimated based on partial or full destruction of cage structures based on the replacement cost of cage structure at its value prior to the disaster. This also includes the repair cost of cage structure prior to its destruction. The loss of stored inputs and accessories were also included under damages. The inputs are valued at farm gate price or market rates.

#### *Losses*

The loss was estimated based the final production of fishes which could have been achieved by the affected units at the time of harvest based on average yields and prices recorded in the previous cropping seasons for different species of fishes.

Preliminary assessment in the flood affected areas revealed that the cages along with fishes were completely washed off in many locations like Gothuruthu, Cheriappilly, Kottuvally and Chathanad in Ernakulam district and Kottappuram and Engandiyoor in Thrissur district whereas partial damage to cages and other infrastructure along with loss of fishes reported in other flood ravaged districts. Most of the affected farms were at final harvest stage yet the farmers postponed the harvest in anticipation of higher returns during the Onam, *Bakird* and *Christmas* festivals. The cage farms in the districts of Ernakulam and Thrissur were the worst affected accounting for an aggregate loss of Rs.9.94 crores. Fish loss contributed the maximum loss in the major flood hit districts of Ernakulam (90%) Thrissur (69%) and Kozhikkode (67%) followed by loss or damage to infrastructure such as cage frames/ freezers/nets/ drums or boats. In Ernakulam district majority of the farmers stocked Asian seabass along with *Etroplus* and *Tilapia* and the highest loss occurred for Seabasss stocks, followed by *Etroplus* and *Tilapia*.

Many of the farmers in Ernakulam district installed Chinese dipnets along with cages which helped them to enhance their revenue through capture based aquaculture. The live juveniles of redsnappers and carangids collected from these Chinese dipnets were stocked in the cages for getting additional revenue. Majority of the Chinese dipnets in the area were also either partially or fully damaged thus exacerbating the woes of the fish farmers. The total economic loss due to damage and loss in the cage fish farming sector in Kerala was estimated at 216.51 crores (Table 2)

Table 2. Loss and damage to cage farms in Kerala due to floods, 2018

| District  | Affected areas  | No of affected units | Fish loss(t) | Loss(₹ lakhs) | Damages (₹ lakhs). |
|-----------|---|----------------------|--------------|---------------|--------------------|
| Alappuzha | Chengannur, Cherthala   | 62                   | 14.88        | 66.96         | 15.14              |
| Ernakulam | Kadamakkudy (Pizhala, Kothad), Gothuruthu, Ezhikkara, Kottuvally(Cheriyappilly) Chendamangalam, Moothakunnam, Aluva and Poothotta | 426                  | 191.32       | 661.22        | 90.89              |
| Kollam    | Chemmakad, Perinad, Prakkulam   | 8                    | 0.144        | 3.57          | 0.12               |
| Kozhikode | Chelanure, Olavanna, Kadalundi, Feroke Kozhikode, Thalikulathure, Vadakara Maniyur, Koyilandy, Keezhariyur Payyoli                | 19                   | 7.15         | 19.16         | 9.7                |
| Thrissur  | Methala(Anappuzha) Kaippamangalam, Mala, Kottappuram, Manalur and Naduvilkkara  | 70                   | 88.25        | 220.07        | 97.21              |
| Total     |   | 585                  | 301.6        | 968.11        | 216.51             |

Source: Estimates by authors and data from State department of fisheries, Kerala

Climate change is causing several catastrophic disasters throughout the world. Many of the recent disasters due to extreme events in India warrant the need for development of a comprehensive disaster preparedness plan for the country. The concept of loss and damage (L&D) of climate change has emerged as one of the emerging work streams in the international climate change regime



(Surminski & Lopez ,2015). The loss and damage associated with climate change impacts needs to be addressed in a comprehensive, integrated and coherent manner (UNFCCC, 2013). Comprehensive adaptation and mitigation strategies to improve climate resilience at state and national levels along with international cooperation and expertise to enhance the knowledge and understanding of risk management approaches for reducing the losses and damages associated with the adverse effects of climate change is very much essential in the future.

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**Johnson Belevendran**

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### Introduction

The fish catch or harvest from marine capture fisheries is in a stagnation phase over the last few years, which has led to reduction in fish catch. The demand for seafood is increasing over the years. In this context, one of the options for additional seafood production is the farming of fishes in the sea cages and coastal saline ponds. The Central Marine Fisheries Research Institute (CMFRI) has developed breeding, seed production and farming technologies for commercially important marine finfishes. As a result of the initiative taken by the CMFRI, many groups are adopting cage farming in the coastal region of Tamil Nadu, Karnataka, Andhra Pradesh, Kerala, Goa, Maharashtra, Odisha and Gujarat states. One of the anticipated issues while expanding the sea cage farming is the environmental degradation and consequent disease problems. In this context, the idea of bio-mitigation along with increased biomass production can be achieved by integrating different groups of commercially important aquatic species which are having varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA) which is gaining importance at global level.

### What is IMTA?

IMTA is a form of aqua farming that utilizes the ecosystem services provided by organisms of low trophic levels (e.g. shellfish and seaweed) raised in appropriate ratio to mitigate the effects of organisms of high trophic levels (e.g. fish) (White 2007, Troell *et al.*, 2003). Integrated Multi Trophic Aquaculture (IMTA) is the practice which combines in appropriate proportions the cultivation of fed aquaculture species (E.g. fin fish / shrimp) with organic extractive aquaculture species (e.g. shell / herbivorous fish) and inorganic extractive aquaculture

species (e.g. seaweed) to create balanced systems for environmental stability (bio-mitigation), economic stability (product diversification and risk reduction) and social acceptability (better management practices).

IMTA has been successfully adopted in Chile, USA, Canada, Europe and many Asian countries. It was reported by Chopin (2006) that under the IMTA systems in the Bay of Fundy, 'Kelp and mussel productions increased by 46 and 50%, respectively, when cultivated in proximity to salmon sites.

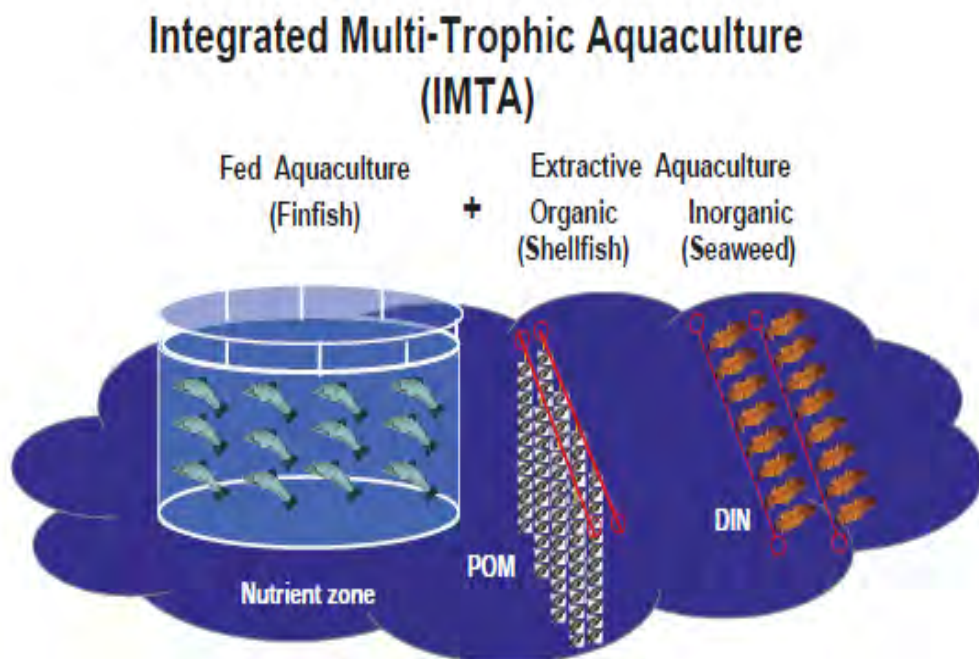


Figure 1. Integrated Multitrophic Aquaculture systems

POM: Particulate Organic Matter; DIN: Dissolved Inorganic Nutrients Source: Chopin, 2006

CMFRI has successfully conducted demonstration of Integrated Multi Trophic Aquaculture (IMTA) under participatory mode with a fishermen group at Munaikadu (Palk Bay), Ramanathapuram district, Tamil Nadu by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*).

#### IMTA Design

A total of 16 bamboo rafts (12× 12 feet) with 75 kg of seaweed per raft were integrated for a span of 4 cycles along with one of the cobia cages. A GI cage of 6

m diameter and 3.5 m depth with 750 cobia fingerlings was integrated with the above seaweed raft system. One complete cycle of seaweed extends for an average of 45 days duration and four such cycles were performed in a row. As a control, a separate set of rafts of the same number were grown in a distant location without any integration with the cages.



Figure 2. Seaweed rafts (16 Nos.) integrated with cobia cage

### **Economic stability**

In one crop of 45 days the seaweed rafts integrated with cobia cage gave a better average yield of 260 kg per raft while the same was 150 kg per raft for the rafts which were not integrated. An addition of 110 kgs of seaweed/ raft was achieved due to the integration with cobia cage farming.

The total seaweed production of the integrated rafts after 4 cycles was 1280 kg, while that of non-integrated rafts was only 576 kg. So, an additional yield of 704 kg of seaweed was achieved due to the integration with cobia cage farming. Although the operational costs of rafts in either case were the same, there was an additional revenue generation/additional net profit of Rs. 26,400 realized with an increased profit margin of 41 per cent through integration of seaweed rafts with cobia cages.



Figure 3. Comparison of seaweed rafts-both integrated (with cobia cage) and non-integrated

Table 1. Comparison of cost and returns of seaweed cultivation with and without IMTA (16 rafts/ one cage/4 cycle)

| Particulars                                      | With IMTA     | Without IMTA | Difference     |
|--|---------------|--------------|----------------|
| Dried seaweed production (for 4 cycle, 16 rafts) | 1280 kg       | 576 kg       | +704           |
| Price of dried seaweed (Rs. per kg)              | 37.50         | 37.50        |                |
| Revenue (Rs.)                                    | 48,000        | 21,600       | +26,400        |
| Costs (Rs.)                                      | 16,000        | 16,000       |                |
| <b>Net Profit (Rs.)</b>                          | <b>32,000</b> | <b>5,600</b> | <b>+26,400</b> |
| <b>Profit Margin (%)</b>                         | <b>67</b>     | <b>26</b>    | <b>+41</b>     |

Moreover there was an increased number (average 90-100 nos.) of newly emerged apical portion/tips in a bunch of harvested seaweed from the rafts integrated with the cobia cages, whereas the same was less (average 30- 40 nos)



from the rafts which were not integrated. The bunches having more numbers of newly emerged apical portion/tips, when used for replanting, will be ready for harvest within 40 days, whereas the seaweed with less numbers of newly emerged apical portion/tips, if used as seed, will be ready for harvest only after 54 days.



Figure 4. Comparison of a bunch of seaweed taken from integrated and non-integrated raft: More numbers of newly emerged apical portion/tips from integrated rafts



Figure 5. Harvested seaweed *Kappaphycus alvarezii* from the integrated raft

The integration of the cage with seaweed also generated favorable returns for the farmers with respect to the finfish production. In a six month production cycle of cage farming of cobia (along with 4 cycles for the integrated seaweed), an average yield of 1,220 kg was achieved with the integrated system in contrast to the non-integrated one where the cobia yield was only 960 kg. The gross revenue generated from the yield (with an average weight of 2.2 kg/ fish and at the rate of Rs. 290/ kg) was Rs. 3,53,800 for the integrated and Rs. 2,78,400 for the non-integrated cages. So, an additional net operating income of Rs. 75,400 was realized from the integrated cage.



Figure 6. Harvested cage farmed cobia fishes from the integrated cages

### Environmental stability

It was found that the organic waste mitigation of integrated system of *Kappaphycus* farming is more efficient than the non-integrated system of farming. Biochemical analysis of water and sediments from the experimental rafts and cages indicated a mutual beneficial effect of seaweeds and cobia in the integrated aquaculture system. The analyses for organic matter load and water quality parameters indicated that the organic wastes from the feed waste and excreta of fish were sequestered by the integrated seaweed. While the sequestration of the organic waste by seaweed acts as a fertilizer for itself, decreased the organic pollution and helps the fish to save and minimize its



energy expenditure towards warding off environmental stress, thus helping it to have better growth rate over its counterpart cultured in non-integrated manner.

The total amount of CO<sub>2</sub> sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 223 kg and 100 kg respectively. Hence there is an addition of 123 kg carbon credit due to integration of 16 seaweed rafts (4 cycles) with one cobia cage (one crop).

Table 2. Comparison of carbon sequestration potential of seaweed cultivation with and without IMTA

| S.No | Particulars  | With IMTA     | Without IMTA  |
|------|--|---------------|---------------|
| 1    | Fresh seaweed production (for 4 cycle, 16 rafts)           | 12800 kg      | 5760 kg       |
| 2    | Average dry weight percentage of the harvested seaweed (%) | 8.75          | 8.75          |
| 3    | Average carbon content (%)                                 | 19.92         | 19.92         |
| 4    | <b>Total amount of carbon sequestered (1)× (2)× (3)</b>    | <b>223 kg</b> | <b>100 kg</b> |

## Conclusion

The innovative farming concept integrated multi-tropic aquaculture (IMTA), introduced by CMFRI can mitigate the potential negative externalities of sea cage farming with simultaneous enhancement in seaweed yield. It also generates additional revenue through increased yields of both cobia and seaweed. This is evident from the increased profit percentages in either case. Many fishermen groups in the Palk Bay region are being benefited through this technology and they are perpetually adopting this technology with their own investment.

## Methodologies for Assessing Socio-Economic Vulnerability due to Climate Change Regime

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### Introduction

The total fish production in India constitutes 6.3 per cent of the global fish production. Fisheries sector contributes to 1.1 percent of the Indian GDP and about 5.15 per cent of the Agricultural GDP (AGDP). The total fish landing in India is 10.16 million ton with 3.59 MT from marine and 6.57 MT from inland sector. Besides providing livelihood security to around 14.5 million dependents, it also ensures the nutritional security of the huge population of India, with around 60 per cent fish consumers. The per capita fish consumption is 5-6 kg, with states like Kerala having per capita fish consumption as high as 30 kg. India exports around 10.51 L tones of fish with a value of 33,442 crores. As per the CMFRI report the valuation of marine fish in India at Landing Center and Retail Center is around 52,807 and 80,018 crores respectively in 2017. With high growth rates, the different facets of marine fisheries, coastal aquaculture, inland fisheries, freshwater aquaculture, cold water fisheries has immense potential to contribute to food, health, economy, exports, employment and tourism of the country.

Even with increasing growth rate, marine fisheries sector and fisheries sector in general is facing many challenges overcoming which will determine the sustainability of fisheries sector. . The challenges include continued technology drive, over capitalization - mechanization, dwindling CPUE, juvenile fishing/discards/illegal fishing, disguised employment, sectoral landings/conflicts, low marketing margin and value addition, lack of fishing rights and management dilemma, lack of institutional credit and climate change. Among these, climate change is a factor having multi-dimensional effects on fish, fisheries and fishermen. It is the critical factor which has the potential to make or break the progressive cycle of sustainability that we are aiming towards. It is important that

we develop an integrated climate change adaptation and mitigation strategy involving all the stakeholders before it breaks the entire system. .

### Climate change and marine ecosystem

The marine ecosystem is constituted by an intricate set of relationships among environment, resources and resource users (Figure 1). Changing climate affects ecosystem in a variety of ways. For instance, warming may force species to migrate to higher latitudes or higher elevations where temperatures are more conducive to their survival. Similarly, as sea level rises, saltwater intrusion into a freshwater system may force some key species to relocate or die, thus removing predators or prey that are critical in the existing food chain. Climate change not only affects ecosystems and resources directly, it also interacts with the general well-being of resource users or community as a whole.

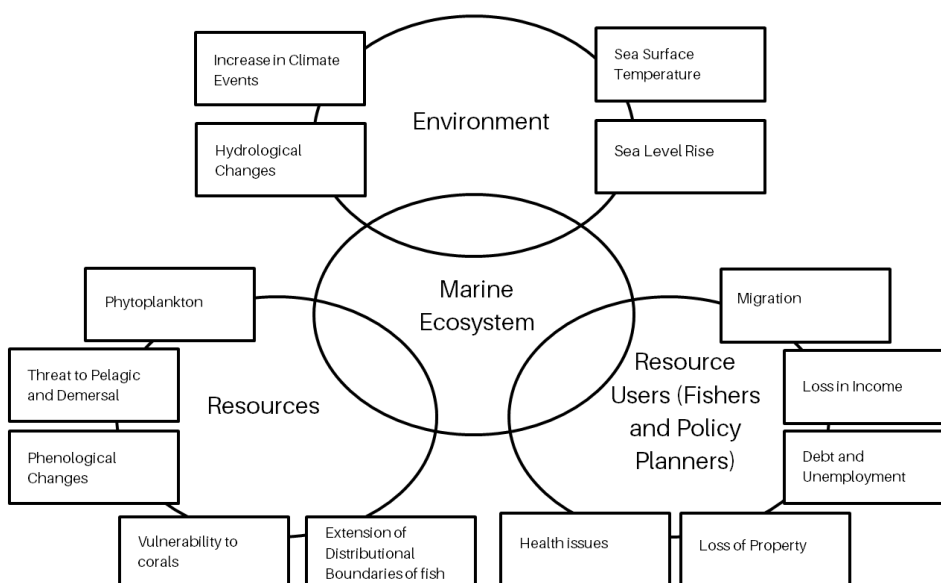


Figure 1. Components of marine ecosystem

#### I. Impact of climate change on environment

Marine ecosystems are not in a steady state, but are affected by the environment, which varies on many spatial and temporal scales. Changes in temperature are related to alterations in oceanic circulation patterns that are affected by changes in the direction and speed of the winds that drive ocean currents and mix surface waters with deeper nutrient rich waters (Kennedy et al., 2002). These processes in turn affect the distribution and abundance of plankton, which are food for

small fish. Understanding the importance and the implication of the climate changes on coastal areas may be one of the major issues for this and next centuries.

Climate changes may, indeed, impact the nearshore marine environment, as coastal areas are very sensitive to the strength and the variability of the meteorological forcings. An increase of a few degrees in atmospheric temperature will not only raise the temperature of the oceans, but also cause major hydrologic changes affecting the physical and chemical properties of water. These will lead to fish, invertebrate, and plant species changes in marine and estuarine communities (McGinn, 2002). Fishes have evolved physiologically to live within a specific range of environmental variation, and existence outside of that range can be stressful or fatal (Barton *et al.*, 2002). These ranges can coincide for fishes that evolved in similar habitats (Attrill, 2002). Estuarine and coastal regions are extremely productive because they receive inputs from several primary production sources and detrital food webs. Yet, these systems present the biota with a harsh environment, forcing organisms to evolve physiological or behavioral adaptations to cope with wide ranging physical and chemical variables. Temperature, along with other variables, causes active movement of mobile species to areas encompassing the preferred range of environmental variables, influencing migration patterns (Rose and Leggett, 1988; Murawski, 1993; Soto, 2002). The predicted increase in major climatic events, such as ENSO (IPCC, 2001), may have drastic effects on fish stocks, especially when combined with other factors, such as overfishing. It has been suggested that reduced survival, reduced growth rate, and diversions of traditional migratory routes can all be caused by ENSO events, exacerbating the effects of intensive harvesting (Miller and Fluharty, 1992). The El Nino phenomenon generates substantial changes in oceanographic and meteorological conditions in the Pacific Ocean, with manifestations impacting the Peruvian coast; this has mainly affected pelagic resources, producing alterations in their biological processes, behaviour, and gradual decrease in their population levels (Valdivia, 1976).

## **II. Impact of climate change on resources**

Climate change will affect individuals, populations and communities through the individuals' physiological and behavioral responses to environmental changes. Extremes in environmental factors, such as elevated water temperature, low dissolved oxygen or salinity, and pH, can have deleterious effects on fishes (Moyle and Cech, 2004). Suboptimal environmental conditions can decrease

foraging, growth, and fecundity, alters metamorphosis, and affects endocrine homeostasis and migratory behavior (Portner et al., 2001). These organismal changes directly influence population and community structure by their associated effects on performance, patterns of resource use, and survival. Climate affects the distribution and abundance of species in ecosystems around the world. In the face of rising temperatures, the ocean may experience variations in circulation, water temperature, ice cover, and sea level (McCarthy *et al.*, 2001). Climate-driven fluctuations in regional temperature can further affect growth, maturity, spawning time, egg viability, food availability, mortality, and spatial distribution of marine organisms (Nye *et al.*, 2009). Also affected by climate change are the size and timing of plankton blooms, a major driver of marine ecosystem function with a direct impact on recruitment success and population sizes (Fischlin et al., 2007).

Studies on the impact of climate change on fisheries (fish species, stock distribution etc.) have been carried out mainly by the CMFRI, Kochi. Investigations carried out by the CMFRI show that different Indian marine species will respond to climate change as follows: (i) Changes in species composition of phytoplankton may occur at higher temperature; (ii) Small pelagics may extend their boundaries; (iii) Some species may be found in deeper waters as well; and (iv) Phenological changes may occur.

### **III. Impact of climate change on resource users**

Climate change poses a great threat to resource users, in particular, the fisher communities who are emotionally attached to their living environment as their livelihood is heavily dependent on sea. The impact of climate change in marine resource users includes, displacement of family members, food security issues, Migration of fisherfolk, fall in income level, seasonal employment, change in employment pattern, increased fishing cost, reduction of fishing days etc.

- a. Demography and Social standards:** Displacement of family members increased over the years, the young generation has a tendency to move out of fishing, Food security issues increased rapidly in recent years. Disguised unemployment is rampant in all sectors since earnings from marine fisheries are not proportionate to the increase in fishers. This has instigated labour migration induced by the earning potential in the distant waters coupled with limited resources in their vicinity
- b. Infrastructure sensitivity:** Increased frequency and severity of storms or weather, and sea conditions are, unsuitable to fishing as well as

damaging to communities on shore through flooding, erosion, and storm damage. There is proximity to hazard areas the fisher household are highly prone to disaster dwellings and the property loss increased over the years.

- c. **Income Effect:** The income levels of fishers decreased substantially over the years. The employment pattern has been mostly seasonal, and alternate avocation options are minimal, there is also economic loss due to loss in number of fishing days. Changed fishing ground caused increased cost of fishing and fish storage. The fuel cost, the cost of fishing gear and boat are increasing significantly over the years.

Vulnerability is a condition wherein the internal ability or lack thereof to cope, recover and adapt to climate stress (Kasperson et al., 2003). Vulnerability has emerged as a central concept for understanding the impacts of climate change and natural hazards, in order to develop adequate risk management strategies. Coastal vulnerability describes the susceptibility of the natural system and of coastal societies (persons, groups or communities) towards coastal hazards. Assessing coastal vulnerability is an important prerequisite to identify the areas of high risk, factors contributing to the risk and the ways to reduce the risk (Brooks, 2005). Vulnerability is multidimensional, dynamic and scale-dependent and site-specific. CMFRI has taken lead in taking up climate change specific research areas for studies and has been instrumental in developing various methodologies to assess the socio-economic vulnerability due to climate change regime.

### **Methodologies for assessing socio-economic vulnerability due to climate change regime**

#### **A. National Innovations on Climate Resilient Agriculture (NICRA)**

National Innovations on Climate Resilient Agriculture (NICRA) is the network project initiated by ICAR for studying the vulnerability impact and adaptation options for Indian agriculture to climate change. The objectives of the NICRA project is to enhance the resilience of Indian marine fisheries sector and mariculture to climatic variabilities and climate change through development and application of suitable management measures and technologies to demonstrate season and site specific technologies on mariculture for adapting to current climatic risks; and to enhance the capacity of fisheries scientists and other stakeholders in climate resilient marine fisheries and mariculture research and its

application. The methodology developed under NICRA for assessing the socioeconomic vulnerability of coastal village households is given below.

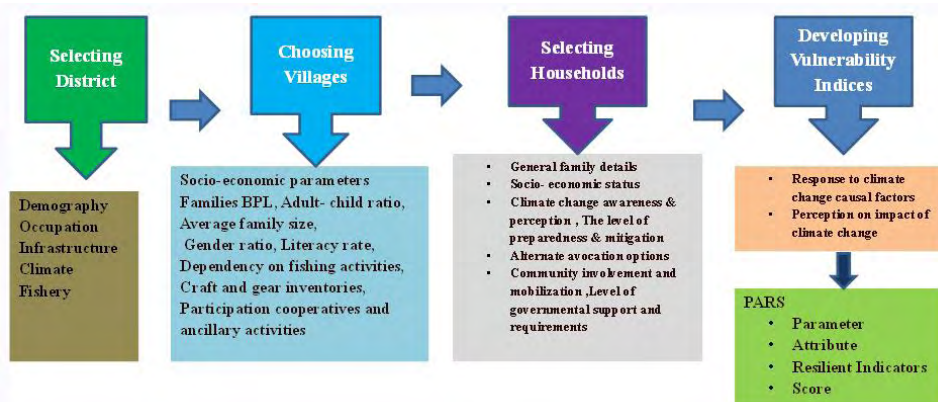


Figure 2. Methodology for assessing the socioeconomic vulnerability of coastal village households

### Parameter, Attribute, Resilient indicator and Score (PARS) methodology frame work

Shyam et al., 2014 constructed the vulnerability indices using Parameter, Attribute, Resilient indicator and Score (PARS) methodology, a conceptual framework developed for assessing the climate change vulnerability of coastal livelihoods under the initiative “National Innovations in Climate Resilient Agriculture” (NICRA). Under this initiative, the vulnerability of 318 fisher households in Alappuzha District of Kerala was assessed using PARS methodology (Shyam et al. 2014). The methodology provides prioritisation and ranking of the different impacts as perceived by the fishers on environment, fishery and socio-economic parameters. The vulnerability indices were worked out for the fisher households. The fisher’s perception revealed that fishery was most impacted followed by economic and environmental impacts. Social impact was the least as opined by fishers. The study indicates that long term effects of climate change aren’t realised/perceived/impacted much among the fisher households. The fishers were more prone to loss in fishing days due to erratic monsoon.

The methodology was employed across the Theme III of IDLAM (Integrated District level Adaptation and Mitigation) and was adopted across the coastal villages of the country. The results suggest a bottom up approach with the proactive participation of the the primary stakeholders awareness by involving

them in disaster preparedness, management and mitigation planning as well as implementation process.

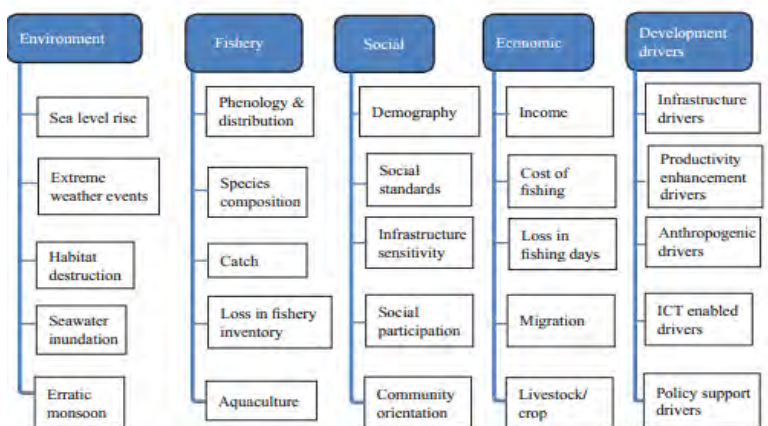


Figure 3. PARS - Climate change perception assessment

## B. Australia India Strategic research Fund (AISRF)

AISRF project, based on two workshops, brought together inter-disciplinary researchers from both India and Australia with expertise in physical, biological, social, economic and governance climate change research and developed a strategic research plan for future collaborative research. The workshops identified that the key physical drivers (e.g. temperature, currents) are predicted to affect species abundance and distributions, develop biological, social and economic indices that can be used to monitor impacts on species, industries and rural communities and investigate options for policy and management of marine resources. By developing a strategic and operational plan, the project focused on developing a collaborative research opportunities that can assist Governments, Industries and Communities prepare and adapt to changes in their marine resources. Society, economic and governance differences between India and Australia provided an exciting opportunity to determine generic and specific issues and to adapt concepts and methods across broad biological and socio-economic backgrounds.





Figure 4. Strategic Research plan

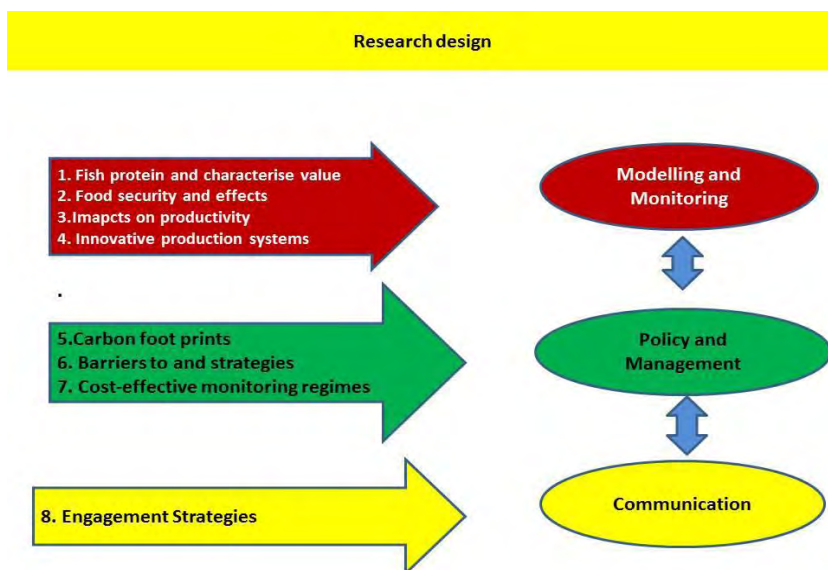


Figure 5. Development of Research / Theme Areas

### C. Global understanding and learning for local solutions: Reducing vulnerability of marine-dependent coastal communities (GULLS)

The CMFRI research project on "Global understanding and learning for local solutions: Reducing vulnerability of marine-dependent coastal communities" (GULLS) under the theme on Coastal Vulnerability was sanctioned under an MoU of Belmont Forum and G8 Research Councils International Opportunities

Fund. Focus areas of GULLS project include Southern Africa, Southern Australia, Western Australia, Mozambique channel, Southern India and Brazil. The GULLS project addressed the Belmont Challenge priorities in the area of coastal vulnerability – specifically the challenges that arise in food security and sustaining coastal livelihoods as a result of global warming and increasing human coastal populations. The project is contributing to improving community adaptation efforts by characterizing, assessing and predicting the future of coastal-marine food resources and identification of suitable adaptation options. The rationale for selection of the focus area included early observation of the impacts, strong incentives to initiate adaptive strategies, developing models for early prediction and validation, developing adaptation options and testing for challenges to be met efficiently and effectively.

### **Identification of climate change hot spots**

Climate change Hot spots –can be defined as the “live labs’ where the manifestations of the climate change impacts are observed “first”. The identification of the climate change hot spots would help policy makers in priority setting and in planning adaptation and conservation measures

The coastal vulnerability assessment in GULLS project underlines, a demarcation between fishery hotspots (based on fish abundance, phenology, distribution, range shifts, recruitment success etc.) and social hotspots (determining vulnerability, displacement, marginalization of traditional community). Consistent with the objectives of GULLS, the activities will be aiming at assessing the current status of the fishery resources and ecosystem services and would attempt at predicting the future impacts of climate change on these resources and services apart from identification of key vulnerable marine species to climate change and assessing the community vulnerability.

The review done in addition to the discussions with the Belmont team resulted in boiling down the hotspot region to South West and South East Region of India. The South East India encompassing Ramanathapuram and Tuticorin districts of Tamil Nadu and South West India consisting of coastal districts of Kerala including Ernakulam, Alappuzha, Kollam and Trivandrum were selected as hotspots.

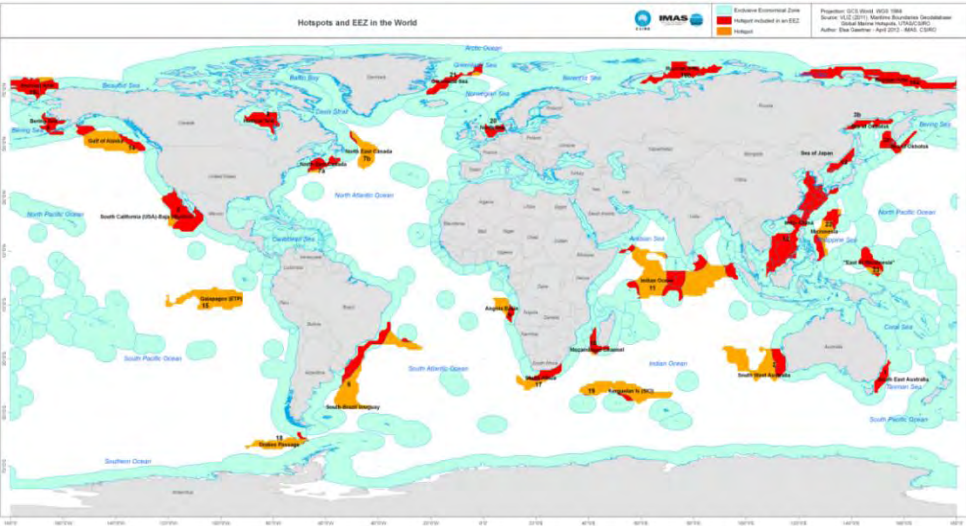
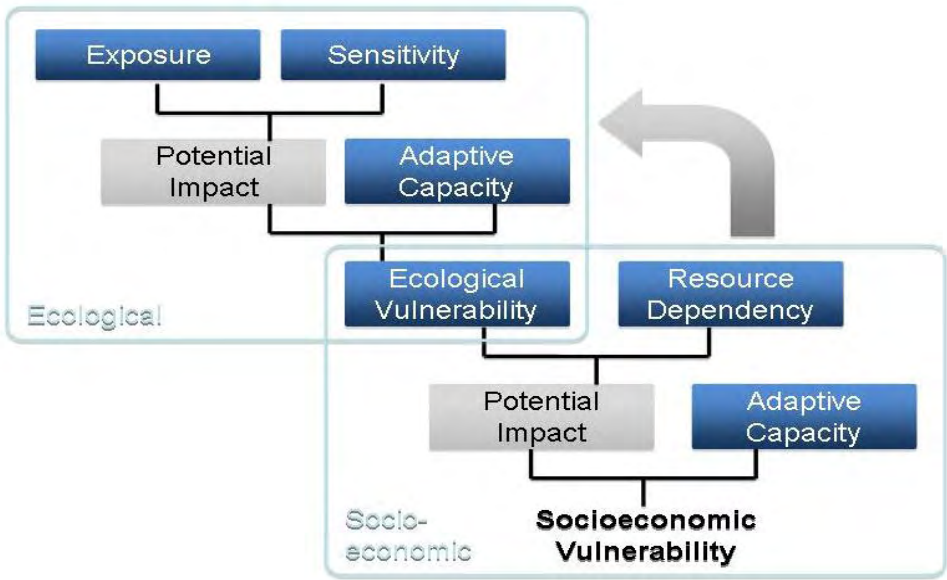


Figure 6. Hotspots - ocean regions experiencing fast warming and those with heightened social tensions as a result of climate change.

**GULLS Vulnerability Model (modified from IPCC)**



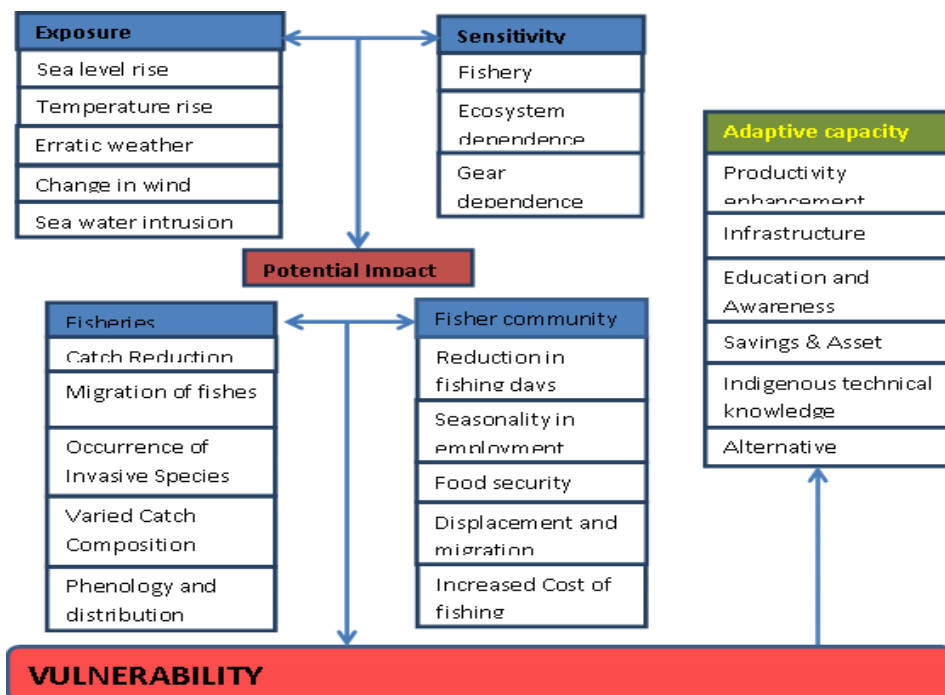


Figure 7. Vulnerability- Key Factors

Vulnerability of coastal regions will be characterized using a linked socio-economic and ecological vulnerability model. The project will be in operation in the different hotspots and will lead to build regional skill-sets that can reduce coastal vulnerability by evaluating and characterizing likely impacts, create predictive systems that will inform decision makers about the expected consequences of coastal changes; deliver alternative options in terms of adaptation and transformation within coastal communities; and to define the long-term implications of selecting a particular option in terms of economic, social and environmental outcomes. Along Kerala coast, two major fishing villages namely Elamkunnappuzha of Ernakulam district and Poonthura of Thiruvananthapuram district in the south west hotspots of India was selected under GULLS project to assess the overall vulnerability of fishery based livelihood due to the impact of climate variation.

A composite vulnerability index approach was used in this study to evaluate relative exposure, sensitivity, and adaptive capacity (Islam et al. 2014). The mean values of the three sub-indices of Exposure (E), Sensitivity (S), and Adaptive

Capacity (AC) were combined to develop a composite vulnerability index by using the following additive (averaging) equation (Islam et al. 2014).

**Vulnerability (V) = Exposure (E) + Sensitivity (S) - Adaptive Capacity (AC)**

The overall vulnerability values indicate that Poonthura village is slightly more vulnerable than Elamkunnappuzha. The proximity of Poonthura village to the sea can be attributed as the major factor contributing the increase in vulnerability compared to Elamkunnappuzha. In addition higher exposure on account of environmental changes, occurrence of drought and shoreline changes is also attributed to higher vulnerability in Poonthura. However, the sensitivity values are high in Elamkunnappuzha when compared to Poonthura due to high social dependence, economic dependence on other resources as well as historical and cultural dependence on fishing. The adaptive capacity of the selected villages were low when compared to exposure and sensitivity values, indicating the urgent need for developing appropriate adaptive interventions. Therefore, more adaptation options like better policy framework, proper planning measures, and effective disaster management techniques should be implemented to increase the adaptive capacity of the fishermen community to climate change. Improvement of natural capital like steps to curb marine pollution, maintaining prey-predator relationship in the oceans, promoting the culture of species in marine habitats (Cage culture), regulation of fishing rights across the Indian seas, extending the period of trawl ban so as to prevent the recruitment of juveniles entering the fishery maybe looked into as major elements while framing adaptation options.

Table 1. Coastal vulnerability Index of selected hotspots

| Region          | Sensitivity | Exposure | Adaptive capacity | Overall vulnerability |
|-----------------|-------------|----------|-------------------|-----------------------|
| Poonthura       | 2.80        | 2.57     | 2.52              | 2.85                  |
| Elamkunnappuzha | 2.67        | 2.70     | 2.57              | 2.80                  |

**CReVAMP**

A new framework titled 'CReVAMP' - "*Climate Resilient Village Adaptation and Mitigation Plan*" conceptualised for planning and implementing village level adaption and mitigation plan which is given in the figure no 8. Consistent with the GULLS project objectives, CReVAMP is developed to identify existing climate adaptation and mitigation- probing alternatives and their trade-offs, sensitizing and improving the resilience of community towards climate change

and initiating a multi stakeholders platform for developing a climate knowledge and information systems. The 'CReVAMP' framework presents major elements and approaches through which the desirable outcome is envisaged across different players including individuals, community and the government. This also offers room for defining the 'elements' and 'approaches' in accordance with the village scenario and also for iterative planning of participatory as well as systems-based approaches under which different activities could be implemented with stakeholder engagement for achieving desirable outcome. Considering the sustainability of the adaption and mitigation activities even after the project period, involvement of the climate change agents in the entire process is vital and we have identified a group of people with representation from different age, gender and experience, encompassing articulate children, proactive youth, experienced fishers and committed women as climate change agents in the project. This framework is centered on people and it would help different practitioners to synergize their thoughts and ideas towards planning and implementing different adaptation and mitigation programs thereby helping the community to become climate resilient. In GULLS project we are adopting an integrated approach which would synergize the knowledge system of scientific and indigenous knowledge between the researchers and different stakeholders of the community. It is a balancing act between (i) 'Top Down and Bottom up Approaches', (ii) Prioritized needs of experts and felt need of the communities, (iii) Scientific Knowledge and Traditional wisdom, (IV) Community Solutions and Policy Solutions. This process would be facilitated using multi stakeholder governance model by bringing different stakeholders together to participate in the dialogue, decision making, and knowledge sharing and there by instigate knowledge generation process within the community during the course of the process. The whole process is directed to create village information system within the community, enable green fishing practices and prepare A&M plan for a community which would in turn helps in community empowerment, thus enabling in building resilient community /Climate Change Informed Fisher Community (CCIF). The CCIF is expected to influence the society and government in decision making and actions related to climate change mitigation and would eventually be able to influence the policy making process.

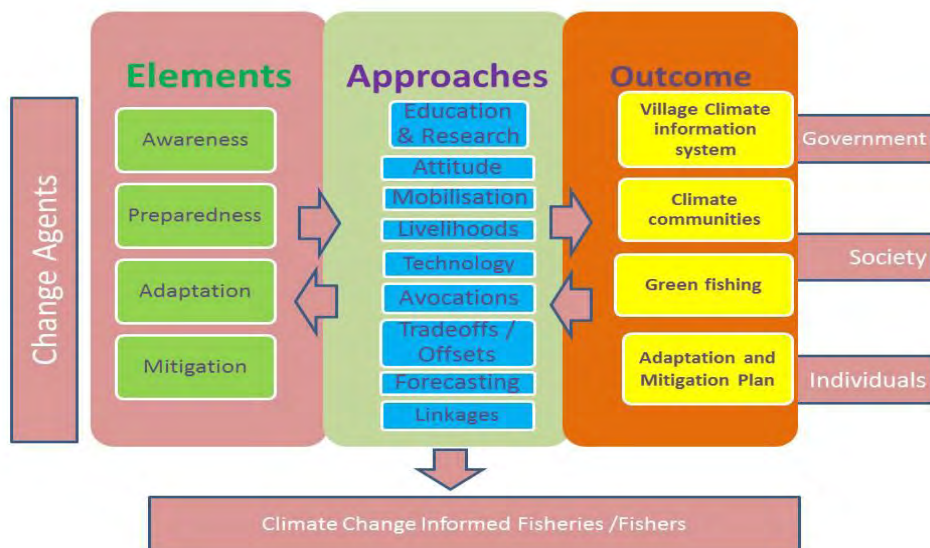


Figure 8. CRvAMP Framework

### Climate change - Way Forward

Climate change as a concept is yet to fully sink in to the conscience of the direct stakeholders in the fisheries sector. It is difficult to delineate climate change out of the many factors affecting fishermen livelihood. It is important that as the persons to directly confront the effects of climate change, they are profoundly involved in the process of developing mitigation and adaptation plans. There is a need to create awareness among the coastal communities with regard to the various repercussions of climate change on their livelihood and how they can play a substantial role in mitigating or reducing the risks posed by climate for them and their future generation.

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## Introduction

The implications of climate change are far reaching and there is a need to develop and implement management plans to boost the resilience of fresh, cold-water, brackish, inland and marine systems, as well as the resilience of infrastructure that allow stakeholders to utilize these systems.

A multifaceted action plan would compose several key elements – targeted scientific, a robust coastal ecosystem, community and industry cooperation and climate sensitive technologies with reduced carbon footprints.

## Adaptation on fisheries habitat

### *Habitat mapping and modeling*

In the context of climate change, research on fish habitat is of high significance. Regional or zone wise (SW, NW, NE, SE) mapping and spatial representation of Indian aquatic habitat and its linkage with eco-system services is identified as a prospective adaptation option. Habitat mapping could be extended specifically for commercial as well as vulnerable species for better conservation, management and sustainable utilization of aquatic resources. Development of regional as well as species level models with representation of oceanic and climatic parameter variation could predict quantitative changes of climatic stressors. Habitat mapping coupled with regional models and continuous monitoring of habitat change provides better adaptation and management of fisheries habitat.

### *Mangrove mapping, conservation and restoration*

India accounts for nearly 3 % of world's mangrove vegetation and C sequestration potential of mangroves and their sediments makes more

significant in the context of climate change. Mangrove ecosystem provides a significant habitat for several aquatic species and act as breeding ground and nursery of valuable biota. Mangroves ecosystem mapping, conservation and restoration is identified as an adaptation option to enhance coastal resilience. Ecosystem productivity could be increased by improving the habitat resulting in beneficial implications on coastal fisheries. This could to a certain extent supplement the fishermen income, thereby enabling them to adapt to vulnerability and loss of fishing days. Mangrove planting in shallow extensive and semi-intensive aquaculture ponds could be done to abate stress due to high temperatures. Besides, it supports artisanal aquaculture activities.

### **Adaptation on fishery stocks**

#### *Stock modeling*

To enhance the resiliency of stocks and their ability to recover from population collapses stock modeling could be done. Several research institutions are capable of carrying this out.

#### *Vulnerability assessment along Indian coastal zones and conservation*

Scientific criteria developed by CMFRI for long term vulnerability assessment of Indian marine fishes could be used to assess the species level adaptability to climate change. Species identified as highly vulnerable could be prioritized for conservation and management strategies. Conservation and fishing protocols based on species stock vulnerability could also be developed so as to enhance the sustainability.

#### *Monitoring, Control and Surveillance (MCS)*

India has effective Monitoring, Control and Surveillance (MCS) mechanism in the EEZ for sustainable usage of oceanic resources. Highly vulnerable stocks identified after scientific analysis could also be brought under MCS for better conservation and adaptation for an optimum period.

### **Adaptation on fish stock availability**

Potential fishing zone could be identified for reducing scouting time and increasing fishing profitability. Activities at fishing zones could be monitored for sustainable exploitation of fisheries resources.

Fish catch forecast models could be developed for Indian coast, so as to enable the fishermen folks and stakeholders to cope up with the stock shift.

New technologies and fishing methods developed could be implemented in the context of climate change and stock availability. Fishermen folks, self-help

groups and other stakeholders could be trained and empowered to augment marine fish production.

Regulation of fishing (fleet size, mesh size, spatiotemporal closure) could be ensured for sustainable fisheries stock utilization.

### **Adaptation on the harvesting sector**

#### *Implementation of Minimum Legal Size*

Catch is of serious concern in the harvesting sector which could be directly attributed to climate change and stock distribution. However, this increases the fishing pressure on vulnerable populations. Hence to bring about sustainability, minimum legal size could be implemented. Better exploitation and utilisation opportunities exist for small pelagics in all the maritime zones

#### *Green fishing protocols for carbon foot print reduction*

Alternative energy usage in fishing operations could be considered. However owing to the direct contribution of fisheries sector directly to food and nutritional security to millions of populations, implementation of shift in operational techniques to reduce the C footprint need to be done only after caution.

### **Adaptation on coastal aquaculture**

#### *Identification of climate resilient species suitable for mariculture*

After experiments on impacts of climatic parameters, stress tolerant species (Silver pompano, Cobia, etc) were identified along with development of technologies for its culture. As climate change had affected wild species distribution and catch, focus on mariculture is an adaptive option and accordingly identification of stress tolerant species is significant. Zone wise commercially valuable stress tolerant species could be identified and cultured for better adaptation.

#### *Adaptations to integrated farming technologies*

Integrated Multi Trophic Aquaculture with farming fish with seaweed and mussel was demonstrated as a successful adaptation measure. Integrated cultivation doubled the weight of seaweed yield and also enhances the fishermen income through co-farming yields as well.

Paddy-fish integrated farming was successfully implemented as an adaptive measure across several states of the nation. Successful demonstration of integrated farming of paddy (pokkali) with finfishes (mullet and pearlspot) in Kerala resulted in profitability (Rs.83,000 per hector per annum) in otherwise

kept fallow paddy fields. Owing to the success, several government agencies initiated schemes for supporting the integrated paddy-fish farming practices.

#### *Regional wetland restoration and implementing scientific fish farming*

Wetland restoration along with incorporation of scientific fish farming at village level was identified as a prospective climate resilient strategy. India had developed a spatial database of wetlands through the National Wetland Inventory and Assessment (Nwai) project, which reports extend of wetlands estimate as 15.26 mha and inland wetlands of the nation as 69.22% of the total wetland area, whereas the coastal wetland accounts to 27.13% and remaining 3.64% includes small wetlands that are less than 2.25ha (National Wetland Atlas). In India 5,55,557 small wetlands were detected and mapped as point features (Panigrahy Sushma et. al, 2012) Developing wetlands of size below 2 ha for fish farming could enhance the regional resilience along with village level food and nutritional security and the surplus production could be channelized to global supply chain. Beyond assessing and developing for reduced GHG emissions, emphatic and comprehensive focus need to be given on enhancing the wetland ecosystem functions such as productivity, habitat, biodiversity, recreation, etc (Rojith and Zacharia, 2016).

#### *Seaweed farming along Indian coasts*

Seaweed farming is identified as a prospective climate resilient strategy. Large scale seaweed cultivation along Indian coastal waters aimed at carbon sequestration, reducing ocean acidification, coastal pollution abatement, co-farming of mussels, oysters and fishes, marine product development, coastal livelihood supplementation and fish feed formulation could enhance the adaptability level of coastal aquaculture. Regional level potential seaweed cultivation zones could be identified and large scale farming could open new horizons in bioproducts and biorefineries industries across the nation.

#### *Development of climate resilient products*

Development of climate resilient products from mariculture residues is another adaptive measure. Biochar with C sequestration ability could be further utilized for aquaculture treatment applications. Biofuel production from micro and macro algae is also a significant climate resilient strategy upon which India is focusing.

### **Adaptation on fishing communities**

#### *Climate change preparedness of vulnerable coastal populations*

The major Climate Preparedness activities (CPAs) recommended are as Increase awareness, preparedness and adaptation among fishers on climate change

related threats to the livelihood through suitable scientific interactions and trainings, Strengthen supplementary avocations available across the different fishing villages to negate the risks and uncertainties of climate change, Scientifically develop location specific elevation levels for new settlement areas for coastal erosion adaptation, Train on disaster management and evacuation plans.

*Strengthen basic amenities in coastal villages*

As extreme climate events negatively impacts on basic needs of coastal population, alternative facilities need to be developed for easy access to food, potable water, sanitation, shelters, etc. Local infrastructure (roads, health supports, etc) could be developed for reducing climate change vulnerability. Since fishermen are forced to move out to deeper areas, protection aids must be made available even for traditional /artisanal fishers. Strengthen seawalls and bioshields (coastal forestry). Regulate unplanned coastal activities which would affect tidal amplitudes in village canals/ riparian areas.

*Increase disaster preparedness*

India had established early warning system and also has a very good natural disaster management system to deal with extreme climatic events. In 2013 a very severe cyclonic storm 'Phailin' equivalent to category 1 hurricane affected around 12 million people of the nation. The cyclone prompted India's biggest successful evacuation in 23 years with shifting of more than 5,50,000 people from coastline of Odisha and Andhra Pradesh to safer places. Successful disaster management plans of the nation could be implemented at each coastal village to cope with even moderate climate change events. Installations of automatic weather stations and similar facilities along with awareness at village level shall enable better weather forecasting and climate change adaptations.

*Development and familiarization of E-commerce technologies for fishermen communities*

Though E Commerce solutions for fish products are available, gap still exists to develop multivendor platform for directly engaging various self-help groups of fishermen communities as multiple vendors. We are ambitiously working out on the concept to develop such a system for fishermen community livelihood improvement and empowerment. Such systems could be in line with the national goal of farmer income increment. The system could fetch better income as well as better marketing for the engaged fishermen communities.

## **National policy and planning**

Climate change risks assessment and preparedness planning could be done through cooperation between governmental and non-governmental sectors. Social media such as radio, television etc. could be used to inform fishers about weather forecasts and warning and also effective engineering could be put along the coast so as to reduce damage to properties and life.

Adapting aquaculture to climate change could be made through selective breeding, regulating the environment and through resilient species. Schemes could be undertaken to set up mariculture farms/ parks, setting up of hatcheries, capacity building of fishers & entrepreneurs to take up mariculture, development of markets so as to increase fish production from coastal areas.

The Department of Animal Husbandry, Dairying and Fisheries has called for a revolution in the fishing industry, identifying the following objectives for the period 2015/16-2019/20:

- To tap the total fish potential of the country in both the inland and marine sector, tripling production by 2020
- To transform the fisheries sector into a fully modernized one, focusing especially on new technologies and processes
- Doubling the income of fishers and farmers, and establishing better marketing and postharvest infrastructure
- Ensuring inclusive participation of fishers and fish farmers
- To triple export earnings by 2020, with a focus on benefits flow to sector stakeholders through deployment of institutional mechanisms such as cooperatives, producer companies and other structures
- To enhance nutritional security of the country

Establishment of weather watch groups and decision support systems could be done on regional basis. Scientific models such as Mass-Balance models, SEAPODYM etc. that help study the relation between climate change and fish population need to be put into practice.

The mitigation measure for carbon release as a part of fishing activities lies in the fuel use and efficiency of boats and vessels. Over the last 25 years there has been an overall increase of 64 percent of carbon dioxide per tonne of fish caught. Measures to reduce carbon footprint include setting emission norms and improving the fuel efficiency of engines.



Life cycle assessments from pre-harvest to post consumer wastes will provide a more detailed picture of the specific emission sectors that require focus to shift to more sustainable production modes. Switching from fuel intensive techniques to alternatives would use less fuel thereby reducing the carbon footprint of fishing practices. For example the fuel use can be reduced from 9l to 2.2l to land 1kg of Norway lobster, if trap fisheries are used rather than the typical trawling method.

New development schemes for enhancing the skills and capabilities of the traditional fishermen to undertake deep sea fishing shall be introduced. Scope of the Marine Fishing Regulation Acts (MFRAs) of maritime States/UTs to include registration of boat building yards, standard design specifications for boats, construction material and procedures for continuous monitoring and control of boat construction could be enlarged, so that this will produce fuel efficient engines and boats could be considered.

Suggested methods to reduce Green House Gas emission include eliminating inefficient fleet structure, improving fisheries management, reducing post-harvest losses, increasing waste recycling, shifting to more efficient vessels and gears, safeguarding stocks and increase their resilience to climate change. Programmes to maintain cleanliness and hygiene in fish landing centres, harbours and fish markets, building up of infrastructure such as harbour based fish dressing centres & processing estates on a public- private partnership so as to reduce post-harvest losses, measures to reduce post-harvest losses through better onboard fish handling could be put into action.

Promotion of mass cultivation of sea plants that can sequester large quantities of carbon could be considered. Of these green algae *Ulva lactuca*, brown alga *Sargassum polycystum* and red alga *Gracilaria corticata* are more efficient. *Kappaphycus alvarezii* in particular shows promise as a sequestering vehicle for carbon.

Artificial reefs that are made of sand filled geotextiles would help protection of coast from the effects of climate change. Fishermen are aware of the variables of climate and their relation to fish catch. Indigenous knowledge can be made useful for reducing the impacts of climate change on fisheries sector.

Effective and timely warning of population decline of fish species would reduce the pressure on the declining population of small and large pelagics. This would help a smoother transition to other fisheries or industries. Pressures on small

pelagics could be reduced by control and regulation of the number of fish meal plants and by implementing National Marine Fisheries Data Acquisition Plan for the timely, reliable & comprehensive data sets of marine fisheries sector.

### **Gaps in knowledge**

Further efforts to be taken always exist, and this is no less true in the case of institutional response to the damaging effects of climate change. Several key areas exist in which to improve the response to the pervasive effects of global warming.

#### *Common knowledge databases*

Common, shared knowledge databases must be made available to researchers across the country. This will streamline research and study in the field of climate change, as significant time is lost on bureaucratic efforts between research organizations during collaborative effects.

#### *Continuous evaluation and fish stock monitoring and dynamic regulation*

Constant monitoring of potential vulnerable species, accompanied by dynamic regulation of the utilization of fish stocks could shift the fishery status of certain fish stocks into sustainable territory.

#### *Historical data records for important fish stocks*

Data records for important species could be compiled and made publically available to increase transparency and allow for greater insight into population and exploitation trends being displayed by commonly harvested species.

#### *Inclusion of scientific committees in policy determination*

Greater involvement of scientific committees comprised of expert panels during the process of policy determination would allow for quicker policy responses to changes resulting from climate change.

### **Institutional Capability**

The Central Marine Fisheries Research Institute falls under the umbrella of the Indian Council of Agricultural Research. Founded in 1947, originally under the Ministry of Agriculture and Farmers Welfare, it comprises seven research centres and three regional centres spread across the coastal areas of the country and is headquartered in Kochi.

Nine divisions including Mariculture, Marine Biodiversity, Fishery Resource Assessment, Pelagic Fisheries, Demersal Fisheries, Crustacean Fisheries, Fishery Environment Management, Marine Biotechnology and Socio Economic

Evaluation & Technology Transfer, one field centre and Krishi Vigyan Kendra work on an integrated approach for improved and timely application of strategies to offset the impacts of climate change on various focal areas of marine fisheries.

The institution is greatly focused on mitigating the adverse effects of climate change and developing new climate resilient strategies for the marine fisheries sector. CMFRI also regularly conducts programmes to disseminate technologies and strategies developed in-house to key stakeholders. Some of the schemes and technologies successfully shared amongst farmers and fishers include:

- Integration of Scientific fin fish farming with traditional Pokkali paddy cultivation,
- Demonstration of small finfish cages for culturing marine fishes
- Development of Technology of Fattening lobster in sea cages to the marketable size,
- Capture based aquaculture for fishermen to harness the positive aspects of climate change
- Identification of climate resilient food crops among halophytes

Some climate resilient strategies to offset the effects of climate change developed by CMFRI include Integrated Multi-Trophic Aquaculture (IMTA), integrated finfish-paddy farming, low cost cage farming, wetland restoration and scientific fish farming, seaweed farming and marine product development, conversion of mariculture residues into biochar, multivendor E-commerce solution for fishermen community, establishment of early warning and weather forecasting system.

### **Research Interventions towards Climate Resilience through National Innovations in Climate Resilient Agriculture (NICRA) Project of ICAR-CMFRI**

ICAR sponsored national level network project to bring out best climate resilient agriculture practices and strategies in each related sectors and ICAR-CMFRI has been entrusted with marine fisheries sector. The climate change research task was undertaken across the total operating centres (Research and Regional) at Cochin, Calicut, Mangalore, Mumbai, Tuticorin, Veraval, Chennai, Vishakhapatnam and Mandapam.

NICRA project could bring several major outputs and outcomes. The project enabled the formulation of scientific criteria to assess the vulnerability of marine species of the nation, which is first of its kind and pave ways for future research in

this direction. Identification of climate resilient species was also established through the project, which is another significant research area. Facilities procured through the research could facilitate climate research progress across the various centres of CMFRI. Research vessel F.V. Silver pompano completes 100 cruises and contributes a lot to oceanic sample collection. Environmental chamber installed at Mandapam is also first of its kind facility in the nation, which boosts the research a lot.

Several climate resilient products development research could also be accelerated through the project. Biofuel and biochar production from aquatic vegetation such as Seaweeds and Water Hyacinth has been attained, which paves way towards exploration of new horizons of climate resilience in marine fisheries sector. Beneficial effects of biochar in fish and paddy growth could also be established through the project.

Assessment of climatic parameters variation along Indian coast and its impact on marine sector revealed changes in distribution, abundance, phenology and trophodynamics of several marine fishes. Some species were found to have positive influence on maturity and spawning season in relation to climate change (SST and rainfall). A scientific criterion was developed for vulnerability assessment of Indian marine fish stocks to climate change and resilience options has been identified. Several adaptation, mitigation and resilience options for Indian marine sector have been recognized through the project. In order to harness the beneficial effects of climate change, resilient species (Silver pompano) for mariculture were identified by experiments. Pearl spot was also identified as a stress tolerant climate resilient species. "Pearl Plus", a feed for pearl spot fish and *Jaiva pokkali*, a brand of organic rice was developed with support of NICRA project. Carbon sequestration potential of seaweed (*Kappaphycus alvarezii*) was confirmed and its large scale farming has been identified as resilient strategy. Several farmers, scientific persons and other stakeholders have been empowered through training and technology demonstrations (Low cost cages, All weather moorings, IMTA, Integrated fish-paddy farming, etc). Technology demonstration units and related infrastructure were also developed through NICRA. 9 National HRD programs for scientists and stakeholders were conducted towards capacity building activities. Compilation of ITK of Indian marine fishermen to climate change has also been brought out. The Fish Farmers Development Agency (FFDA) under the state government has initiated a scheme - Integrated fish farming in Pokkali fields - in collaboration with NICRA and KVK to popularize the technology among farmers of Kerala.

NABARD also sanctioned Pokkali Farmer Producer Company (FPC) as an outcome of the NICRA technology demonstration.

A multivendor E-commerce website hosted as [www.marinefishsales.com](http://www.marinefishsales.com) and associated android application 'marinefishsales' for use in mobile phones has been developed to enable direct sales between fishermen communities and customers. The multivendor e-commerce platform focuses on income enhancement for coastal fishers and farmers. The innovation incorporated is that, in contrary to typical e-commerce ventures where single firm or company as major profit beneficiary, the developed e-platform envisions multiple fishermen self-help groups (SHGs) as beneficiaries. This may be the first instance that a Govt. institution in fisheries sector facilitates the E-Commerce solution, thereby undertaking the greater role to address grass root level climate change adversities through income improvement and livelihood security improvement. Govt. of Himachal Pradesh express interest to implement the similar at their state and enquired for our technical assistance, which was readily agreed upon.

Technical discussions are in final stage with Space Application Centre (ISRO) to collaboratively develop a Webportal and Mobile for data collection of small (<2.2ha) wetlands of the nation. The realization could be revolutionary towards management and continuous monitoring of national regional wetland ecosystem.

### **Research Ready for Deployment**

Following research outputs are ready for deployment or upscaling through NICRA project, which could enhance climate resilience of Indian Marine Fisheries

- Innovative low cost cages for open sea cage culture along Indian coast
- Identification of temperature tolerance in species: silver pompano and pearl spot
- Integrated Multi-Trophic Aquaculture (IMTA) practice
- Integration of fin fish culture with paddy farming
- Biochar from seaweed and water hyacinth for aquaculture applications
- Prototype development of carbon dioxide flow regulator & recorder
- Scientific criterion for vulnerability assessment of marine fishes to climate change
- Multivendor E-Commerce website and android app towards income improvement for fishermen communities
- Biofuel production from seaweed and water hyacinth

## **Conclusion**

Climatic resilience of the marine sector could be attained and the adaptation and mitigation options explored are feasible for time bound implementation. However, more research support could bring these strategies to village level. Climate smart coastal villages could directly contribute towards food and nutritional security of millions and the research interventions in this direction could bring significant improvements. Technology development and empowerment of fishing communities could bring significant changes in the livelihoods as well as national contributions of fisheries sector. E-commerce solution being developed through the project, provides opportunities for the involvement of SHGs of fishermen communities, which could result in the attainment of national goal of farmer income improvement/ doubling. Integrated farming methods are more economically feasible and policies need to be accordingly framed to undertake aquaculture, agriculture and farm tourism as a comprehensive package rather than depending on single sector.

*(Adapted portions from own paper SAARC Country Paper - India)*

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## Embedding Environmental Factors into Stock- Recruitment Relationship – An Overview on Semiparametric Ricker Model

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The environmental factors drive the productivity of marine fish stocks and the recent studies have shown that in the coming years many stocks will be increasingly affected by climate change including global ocean warming, ocean acidification, oxygen loss and other long-term and more regional environmental changes such as salinity, nutrient redistribution or eutrophication and pollution (Roessig *et al.* 2005; Cochrane *et al.* 2009; Hollowed *et al.* 2013; Portner *et al.* 2014). These factors influence marine ecosystems, marine organisms and fish stocks not only through direct impacts on individual physiology and life history but also indirectly via changes in primary productivity or ecological interactions, spatial configuration of habitats or planktonic larval transport (Doney *et al.* 2012).

One of the main ways that the environment influences fish population dynamics is by modulating recruitment, usually in the form of young of the year survival. Explicitly including environmental variables underlying this modulation into stock assessments can help determine whether changes in recruitment are a result of changes in spawning-stock biomass or changes in recruit survivorship to the population structure (Schirripa *et al.* 2009). Numerous studies reported in the fisheries literature attempt to explain the effects of various environmental factors on recruitment (Sutcliffe, 1973; Drinkwater, 1987; Leggett *et al.*, 1984, Carscadden *et al.* 2000, Chen & Ware 1999, Chen 2001, Chen and Irvine 2001, Levi *et al.* 2003, Mikkelsen and Pedersen 2004, Sinclair & Crawford 2005, Megrey *et al.* 2005).

This lecture note aims at giving an overview on a semiparametric model developed by Chen and Irvine (2001), which incorporates environmental and fishery data to analyse stock-recruitment relationships. Unlike traditional stock-recruitment models that assume a log-linear relationship between recruitment

and environmental and fishery variables, this model uses a nonparametric smoothing algorithm, which helps to quantify the underlying empirical relationships and enables more accurate parameter estimates.

Ricker in 1975 proposed an exponential functional relationship to relate the spawning stock with recruits and it is represented as

$$R_t = S_t e^{[a-bS_t]} \quad (1)$$

where  $R_t$ ,  $S_t$ ,  $a$ ,  $b$  describe recruits and spawning stock at time,  $a$  and  $b$  are the population productivity at low density and capacity limited by density-dependence, respectively. These parameters can be estimated using standard linear regression analysis. It is assumed that recruitment is log-linearly distributed, then the revised form is

$$\log \frac{R_t}{S_t} = a - bS_t + \varepsilon_t \quad (2)$$

Where  $\log \frac{R_t}{S_t}$  is the response ( $y_t$ ) of the linear model that represents the recruitment rate per unit of spawning biomass, and  $\varepsilon_t$  is the Gaussian error, such that  $\varepsilon_t \sim N(0, \sigma^2)$ . The main biological assumption of the Ricker model is that high values of  $b$  cause an over compensation, reducing survival of pre-recruits at higher spawning stock size. This does not occur with other stock recruitments models. Chen & Irvine (2001) extended the Ricker model to include environmental variables as follows:

$$y_t = a - bS_t + \sum_i c_i Z_{i,t} + \varepsilon_t \quad (3)$$

where  $Z_{it}$  with  $i \in \{1, \dots, k\}$  represents the environmental variables measured at time  $t$ .

Equation (3) can be expressed in terms of linear regression as follows:

$$y_t = x_t^T \beta + Z_t^T \gamma + \varepsilon_t \quad (4)$$



where  $y_t$  corresponds to the response vector, which in population theory represents an approximation to the population productivity,  $\beta = (a, -b)^T$ , and  $x_t = (1, S_t^*)$  represents the vectors for biological and spawning biomass parameters while  $\gamma = (c_1, \dots, c_k)^T$  and  $z_t = (Z_{1,t}, \dots, Z_{k,t})$  are the values for a group of  $k$  parameters and predictors associated with environmental effects. It is assumed that predictions spread around an additive error of the form  $\varepsilon_t \sim N(0, \sigma^2 I)$ , where  $I$  is the identity matrix for the group of parameters (Espindola *et al* 2016).

Although the Extended Ricker Model parameter (equation 4) can be estimated using multiple linear regression, a number of relevant works (Hilborn 1985, 1992; Jacobson and MacCall 1995, Stocker *et al.* 1985, Fargo and McKinnell 1989, Chen and Irvine 2001) have shown that relation between  $y_t$  and  $z_t$  may take different functional forms that clearly fail the assumption of log-linearity.

Chen & Irvine (2001) proposed another form for relaxing the log-linearity assumption between  $y_t$  and  $z_t$  by implementing a non-parametric function,  $g(\cdot)$  for the co-variables  $z_t$  to include in the Extended Ricker Model such that  $z_t \rightarrow g(z_t)$ . Thus, the vector  $z_t = (Z_{1,t}, \dots, Z_{k,t})$  can be represented in an additive form through  $(z_t) = \sum_{i=1}^k g_i(Z_{i,t})$  which defines a group of functions  $g(\cdot)$  that can be solved non-parametrically, thus avoiding the use of parameter vectors such as  $\gamma = (c_1, \dots, c_k)$ . Then the model can be rewritten as:

$$y_t = x_t^T \beta + g(z_t) + \varepsilon_t \quad (5)$$

where  $g(z_t)$  is the non-parametric term, for which in the theoretical approach of Generalized Additive Models (GAM) is commonly used as smoothing technique. The equation 5 includes two components, where the first involves a parametric term  $x_t^T \beta$  equivalent to the right side of the Ricker Model, while the

second corresponds to a non-parametric term  $g(\cdot)$  that represents the environmental variables. Thus,

$$y_t = f(x_t) + g(z_t) + \varepsilon_t \quad (6)$$

represents a semi-parametric version of the Ricker model. This approach was applied by Chen and Irvine (2001) to southeast Alaska pink salmon (*Oncorhynchus gorbuscha*) with sea surface temperature as the environmental variable and West Coast Vancouver Island herring (*Clupea harengus*) with sea surface temperature and hake biomass as two environmental variables. Results from diagnostic tests indicated that semi-parametric version of the Ricker model performed better than the traditional Ricker model and Extended Ricker model. The recruitment rate was modelled in relation to spawning biomass and to sea surface temperature (SST) for the jackmackerel (*Trachurus murphyi*) population off the Chilean coast using the Ricker model by Espindola et al (2016). The results showed that inclusion of SST improved the fit of the recruitment model. They have concluded that incorporating an environmental variable into stock-recruitment relationships may be a promising method for simultaneously considering effects from fishing and the environment, and is particularly relevant for managing fisheries in light of climate change.

In an ecosystem or fisheries management context, however, what often matters most is not necessarily how the climate or ocean abiotic conditions will change, but how the biological components of an ecosystem might respond to environmental change (Payne et al. 2016). To answer these types of questions, it is necessary to combine or integrate the environmental factors with models of population dynamics and fish stock assessment.

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### **Climate induced variations in natural populations**

Populations of marine organisms respond to environmental and climatic fluctuations depending on the dynamics internal to each population, trophic interactions and several other extraneous factors. Due to the multitude of factors the relationship between an ecological or physiological responses and climatic fluctuations are often confounded. But the effects of climate change have become more important recently due to the rise in temperature levels in the oceans of the world and it is imperative to understand the relationship between climatic forcing and organismal responses. The first level of response to any extraneous factor is at cellular level or at the level of genome. Environment mediated selection plays a major role in bringing about adaptive evolution in response to a changing climate. The techniques in genetic and genomics can be used to understand climate mediated selection and evolution at individual, population and ecological levels.

Organismal evolution to changing climate takes place either by exploiting new resources in the new conditions or by tolerating the conditions to which it is not optimally adapted. Range expansions to temperate latitudes have been explained in many species of fishes in response to a changing climate and this takes place in order to utilize the novel resources. Another adaptive mechanism to utilise novel food resources is to extend the life cycle events or phenology which also has been recorded in many marine organisms.

Even though marine organisms can adapt to stressful conditions by range expansions, many sedentary organisms like mussels, clams and oysters have to face the effect of environmental stressors by tolerating conditions which are not optimal for their survival. The conditions may be extreme temperature levels,

ocean acidification, increased or decreased levels of salinity and many other factors. Such extreme conditions may select for altered spawning time or other phenological changes like flowering time in the case of plants. Organisms may change to altered food resource or their sex ratio may get affected due to temperature fluctuations.

The genetic composition of an organism can be affected by changes in allele frequencies for adapting to altered environmental conditions. If an allele provides tolerance capacity to increased temperature conditions in a population, the frequency of that allele will increase in populations over time as it provides improved fitness. But instead of a genetic change, phenotypic plasticity will also bring about better fitness to a particular environment. Phenotypic plasticity does not involve any change in the genetic constitution of an organism. Instead, same genotypes may exhibit different phenotypes to suit to that particular environment and varying gene expression patterns may play a role in bringing about phenotypic plasticity. The change in allele frequency can also bring about phenotypic plasticity which is regulated through complex networks and pathways.

### **Genetic and genomic methods for investigating climate mediated adaptive evolution**

Genome scans, transcriptome profiling, association and mapping analysis in addition to candidate gene based approaches facilitate detection of loci important in adaptation to a changing climate. Several investigations have proved that adaptive evolution at genetic level is possible in genes which influence traits like body size, thermal responses, reproductive timing and dispersal. In addition, epigenetic changes which are heritable also will bring about climate mediated evolution.

Genome scan approaches can be used to undertake population level comparisons and detect differentiated gene regions as against expected from neutrality using large number of markers. Thus the effects of selection can be differentiated from population level processes. Clinal comparison of populations collected along clines will provide information regarding selection in response to geographic variations. But delineating the effects of climate change from other effects needs cautious approach.

Microarrays can be employed to hybridize DNA from highly diverged areas of the genome which may involve cline ends and this provide important information regarding parts of the genome involved in adaptive divergence. Candidate

genes linked to adaptive divergence can be studied along gradients based on known polymorphisms and effects on genes can be investigated through functional analysis.

Transcriptomic responses could be studied across gradients to understand differential gene expression patterns and to identify gene and gene networks that are differentiated between populations and cline ends. Mapping of quantitative trait locus can be carried out for strains which have been made homozygous for further comparison of quantitative traits among clines.

Epigenetic mechanisms have been presumed to play a major role in environment mediated gene expression and heritability of the acquired traits. Epigenetics refers to inherited changes in gene expression without variations in gene sequences. Several epigenetic mechanisms have been proposed like methylation of cytosine, modification of chromatin structure and changes in gene regulation induced by small RNAs. Phenotypic traits can be transferred from parents to offspring epigenetically without any change in gene sequences which is a very rapid form of adaptation. Stressful conditions lead to epigenetic alterations which mobilize transposable elements causing genetic modifications.

### **Next Generation sequencing methods for rapid detection of adaptive variation**

Next generation sequencing methods refer to a variety of advanced techniques used to decipher the genetic code; Adenine, Thymine, Cytosine and Guanine. Massively parallel sequencing has been made possible by the advent of NGS techniques as compared to Sanger sequencing.

### **Second Generation Sequencing techniques**

#### *The Roche 454 platform*

Roche454 platform/pyrosequencing was the first advanced next generation sequencing platform. DNA libraries can be constructed by any method which gives rise to a mixture of short, adaptor flanked fragments followed by emulsion PCR for clonal amplification of target sequences. Sequencing reactions are carried out using pyro-sequencing method. Sequencing by 454 produces reads of good read lengths and it can produce approximately 4,00,000 reads per instrument with lengths of 200-300bp. Homopolymers will increase the error rate and the most common error type is insertions and deletions.

### *Illumina Genome Analyzer*

Illumina Genome Analyzer is the most popular advanced sequencing machine. Any method can be employed for production of libraries giving rise to a mixture of adapter-flanked fragments which are several hundred base pairs in length. A bridge PCR is used to amplify sequences. Many million clusters are amplified to specific locations within each of eight independent lanes on a single flow-cell and eight independent libraries can be sequenced in parallel at each run of the instrument. Read lengths of upto 35bp are possible currently with higher error rates at longer reads. Most common error type is substitutions.

### *AB SOLiD*

In AB SOLiD, sequencing can be carried out by any method, which gives rise to a mix of short, adaptor flanked fragments. Using emulsion PCR clonal sequencing is carried out and amplicons captured to the surface of 1 $\mu$ m paramagnetic beads. Sequencing by synthesis is carried out using DNA ligase.

### *HeliScope*

Clonal amplification is not required in HeliScope. Sequencing by synthesis is carried out in HeliScope with the help of a highly sensitive fluorescence detection system which carry out direct interrogation of single DNA molecule. Random fragmentation along with poly A-tailing is carried out for preparation of template libraries which are subsequently captured to surface bound poly-T oligomers by hybridization producing a disordered array of primed single molecular sequencing templates. Template dependent extension of surface-captured primer-template is facilitated by adding DNA polymerase and a single species of fluorescently labelled nucleotides at each cycle.

## **Third Generation Sequencing Technologies**

Third generation sequencing technologies are characterised by novel chemistry, less operation time, desktop design and reduced operation cost. Pacific Biosciences real time single molecule sequencing (PacBioRS), Compete Genomics combined pre anchor hybridization and ligation (cPAL) and Ion Torrent of Life Technologies, Inc. are the major third generation sequencers. Third generation sequencing is also known as long-read sequencing which read nucleotides at single molecule level unlike second generation methods which require breaking of long fragments of DNA to small pieces and inferring nucleotide sequences by amplification and synthesis. PacBioRS is a real time single molecule- single polymerase sequencing platform capable of producing reads upto 1000bp. The chips comprise zero-mode wave guided (ZMW) nano



structures consisting of holes of size 100nm. Sequencing by synthesis is carried out in these holes by DNA polymerase enzyme with the help of phospholinked nucleotides which are labelled with fluorophores and introduced sequentially. The nucleotide incorporation kinetics can also be monitored using this instrument which helps to gather epigenetic information in the future.

Complete Genomics employ a combined approach of probe-anchor hybridization and ligation sequencing (cPAL) with the highest throughput among third generation sequencers. The method employs rolling circle amplification of small DNA sequences into the nanoballs form and further the sequence of nucleotides determined by ligation method. Using this approach, several DNA nanoballs could be sequenced per run with low costs. Ion Torrent technology is one of the most versatile and cheap methods and at present this equipment is supplied as a personal genomic machine (PGM). This benchtop instrument is being used widely by researchers and medical practitioners. The technology is based on proton release during nucleotide incorporation by DNA polymerase.

#### **Fourth Generation Sequencing Technologies**

Fourth generation sequencers like portable MinION machine, the benchtop GridION and high-throughput, high sample number PromethION offered by Oxford Nanopore systems are based on nanopore technology. These sequencers can sequence the entire genome of any organism rapidly and with very low cost. Nanopore based technologies originated based on the idea of coulter counter and ion channels. When an external voltage is passed through, particles which are smaller than pore size are passed through the pore and pores which are of nanometer size can be embedded in a biological membrane or in solid state film and consequently separating the reservoirs which contain conductive electrolytes into cis and trans compartments. When voltage is applied, electrolyte ions in solution will move through the pore electrophoretically generating ionic current signals. When negatively charged DNA molecule in the cis chamber blocks the pore, the current gets blocked interrupting the current signal. Then the physical and chemical properties of the target molecules can be calculated by statistical analysis of the amplitude and duration of current blockades which occurred transiently from translocation events.

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**Concept of Indigenous Technical Knowledge (ITK)**

Indigenous Technical Knowledge (ITK) is the local knowledge – knowledge that is unique to a given culture or society. It contrasts with the international knowledge system generated by universities, fisheries, animal husbandry research institutions and private firms. It is the basis for local-level decision making in agriculture, health care, food preparation, education natural resource management and a host of other activities in rural communities (Warren 1991). ITK is the information base for a society, which facilitates communication and decision making. Indigenous information systems are dynamic, and are continually influenced by internal creativity and experimentation as well as by contact with external systems.

Indigenous Technical Knowledge (ITK) with respect to climate change in fisheries can be operationalized as the knowledge/cognitive capital of the fisher folk with respect to prediction/forecasting of various weather parameters and prediction of different types of fish availability and their catch based on their mental models with respect to various perceived changes in the weather parameters.

As a summary of various definitions, the term indigenous technical knowledge may be denoted mainly as a tacit type of knowledge that has evolved within the local (grassroots) community and has been passed on from one generation to another, encompasses not only local or indigenous knowledge, but also scientific and other knowledge gained from outsiders.

**Indigenous Knowledge (IK):** is the participant's knowledge of their temporal and social space. Indigenous knowledge as such refers not only to knowledge of indigenous peoples, but to that of any other defined community.

**Indigenous Knowledge System (IKS):** delineates a cognitive structure in which theories and perceptions of nature and culture are conceptualized. Thus it includes definitions, classifications and concepts of the physical, natural, social, economic and ideational environments. The dynamics of the IKS takes place on two different levels, the cognitive and the empirical. On the empirical level, IKS are visible in institutions, artefacts and allied technologies.

**Indigenous Technical Knowledge (ITK):** is specifically concerned with actual application of the thinking of the local people in various operations of agriculture and allied areas.

**Belief:** change in behavior of insects, animals and vegetation indicating a forthcoming event without any scientific rational but be true in happening.

**Innovation:** outside the area of ITK, but scientifically based development of practices using the locally available resources to solve specific problems.

In the emerging global knowledge economy a country's ability to build and mobilize knowledge capital, is equally essential for sustainable development as the availability of physical and financial capital. The basic component of any country's knowledge system is its indigenous technical knowledge. It encompasses the skills, experiences and insights of people, applied to maintain or improve their livelihood. ITK is developed and adapted continuously to gradually changing environments and passed from generation to generation and closely interwoven with people's cultural values. ITK is also the social capital of the poor, their main asset to invest in the struggle for survival, to produce food, to provide for shelter or to achieve control of their own lives.

The marine fisheries scenario in India presents a picture of heterogeneity sacrosanct with a population of four million marine fisher folk, residing in 3, 288 marine fishing villages in 9 maritime States and 2 Union territories (**Marine Fisheries Census, CMFRI, 2010**) ceremoniously contributing to the country's total marine fisheries production of 3.32 MT. (Sathiadhas et.al, 2012), accounting for a foreign exchange earnings of Rs. 10,000 crores. (2009-2010)

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### **Informal research tools for investigating ITK**

**Semi-structured interviews:** Semi-structured interviews allow the participants more scope to investigate what people know and to follow up topics of interest as they arise in the discussion. They can be used with groups and individuals.

**Group (focus) interviews:** Group interviews provide exchanges between participants with differences of opinion which can often lead to greater insights into people's perceptions. Care is required over the composition of the group so that as many participants as possible feel free to express their opinions, especially those with less status who may be better interviewed in a separate group or individually.

**Key informant interviews:** 'Experts' – those identified by local people as having specialist knowledge – may be interviewed taking care that they do not only include those with formal education and access to scientific knowledge.

**Field visits and transects:** These combine observation and discussion and are useful in allowing the farmer or respondent to point things out *in situ*. They may also provide a more relaxed atmosphere than a group meeting, making communication easier.

**Field observations** These are useful for comparison of actual practice to the 'norms' presented in group discussions or interviews.

**Mapping, diagramming, ranking exercises and games:** These can be used to elicit farmers' perceptions, including spatial conceptions, definitions, classifications and boundaries. Tools include participatory mapping, ranking of importance, comparing characteristics using pairwise ranking diagrams, seasonal calendars and network diagramming.

**Local classification systems/taxonomies:** This is quite a difficult area, involving the identification of local terms, then asking local people to sort and group the

categories, identifying common features and contrasts in the context of the wider language and cultural system.

**Cultural expression:** The content of songs, poetry and speeches on celebrations and public occasions can reflect significant messages and social values. Surveys which relate the respondents' knowledge and attitude to their resulting practices are often known as knowledge, attitude and practice (KAP) surveys.

### **Structured questionnaires and knowledge tests**

Structured questionnaires and knowledge tests have, conventionally, been used by agricultural extension researchers and others to find out about how much local people know. However, such a quantitative approach is not usually a good starting point for studies of LPK, unless the researcher already has an in-depth knowledge of local perceptions and practices. Imposing the rigid structure of a questionnaire implies that the researcher already knows enough about people's perceptions and practices to be able to write specific, unambiguous and comprehensible questions. In practice, these questionnaires may reveal whether the respondents understand scientific terms but provide little information on what the respondents' own ideas might be. Often the results are scored like a knowledge test. If a respondent's answer differs from scientific knowledge or recommended practice it may be classed as 'wrong' and he or she may be considered as having no knowledge. However, structured surveys can have a useful role in following up and verifying hypotheses generated using rural appraisal and other qualitative methods. For example, if it has been found from group interviews that farmers think that certain weeds are good indicators of soil fertility, then a carefully worded questionnaire can be used to determine how widespread this knowledge is.

### **Methodology**

Under the National Initiative on Climate Change (NICRA) Project, it was decided to document the Indigenous Technical Knowledge with respect to climate change. A number of Indigenous Technical Knowledge has been collected in marine fisheries, but none so far has been collected in the realm of Climate Change. The study was conducted from April 2011 to March, 2012 in the eight coastal States of Gujarat, Maharashtra, Karnataka and Kerala along the east coast and West Bengal, Orissa, Andhra Pradesh, Tamil nadu along the west coast. A well-structured interview schedule was used for documentation of the ITKs. Participatory Rural Appraisal methods such as Participatory diagramming,

Participatory transects, Rapid Rural Appraisal techniques, use of Key informants and focused group discussions and interactions were used for the study.

After the documentation of the ITKs at the field level, it was decided to conduct a write shop by inviting scientists, who were involved in the data collection from the eight coastal states, fisher folk from whom the ITKs were documented, fishermen representatives and local leaders. The write shop was conducted at the Mangalore Research Centre of CMFRI from 22-03-2012 to 24-03-2012. The main aim of the write shop was to bring out a publication in a very short time simultaneously ensuring that every possible information collected was verified by the scientists and end users, discussed at length and classified it as an ITK, based on scientific rationale, belief which defies scientific explanation but found/observed to truly occur under field conditions and agreed upon and endorsed by a larger populace.

**The following are the list of ITKs collected from the respective coastal States of India.**

**Karnataka**

- During new moon fish availability is more.
- When wind blows from west side to shore, fish availability is more.
- Winds blowing from south to north coupled with appearance of white seagulls is indicative of rough seas and impending cyclone.
- If wind blows from north east direction, sea becomes rough in next few days and few catches are obtained.
- Arrival of black cormorants from sea towards shore indicates the presence of strong water currents.
- When sea water is turbid upwelling may occur.
- Flying of White Sea gull above the sea, is an indication of the presence of sardine shoals.
- When colour of sea is blue it indicates less fish availability.
- Appearance of mud banks (*Pallikhe*) is indicative of plenty of fish availability, beyond *Pallikhe*, sea is rough and inside the *Pallikhe* sea is calm.
- Three days after coastal upwelling more fishes are caught.
- When sea water becomes thick during rains, fishes are not visible.
- Appearance of zooplankton in mud is a prediction of impending cyclone.

- Appearance of White Sea gull (*Thora hakki*) two days ahead, is indicative of rough sea condition.
- When clouds move from east to west direction and when black sea gull is seen with the clouds it indicates impending storms and coastal upwelling.
- Presence of dark patch at sea when observed from the shore, is indicative of higher wind speed.
- Fishermen say that when their feet goes down in sand while walking along sea shore it is an indication of impending cyclone within 2-3 days' time.
- When halo occurs around moon, more water currents observed.
- When stars at night become dim, there will be more wind speed.
- If during night time, fog is present, the following day (next day) temperature will be more.
- Presence of wind blowing from south (south wind) is a prediction of impending rains.
- If windy day is followed by turbidity of waters at sea, the next day, there will be poor fish catch.
- If wind blows from south, fishes will be less, if it blows from north, fish availability will be more, if wind blows from north east, mackerel catch will be more.
- If during rains, Sea otter makes its appearance it is an indication of less fish availability.
- Change of sea colour from green to white is indicative of higher wind speed.
- Appearance of small black heron flying above sea surface indicates arrival of cyclone 15 days later.
- When winds blow from south west direction during the time of rains, more fishes are observed to come ashore.
- Appearance of black worms on sea surface is an indication of occurrence of cyclone two days later.
- When dragon fly (*Erunti*) come in flocks from southern direction and proceeds to north it is an indication of the arrival of storms within two days.
- If shoals are seen arriving from south west direction, than it is an indication of sardine, anchovy and mackerel catch.
- When north wind blows all fishes go into deeper waters.



- When light gnats are seen in bushes and plants at night, it is an indication of impending cyclone two days later.
- When bubbles appear from below the sea surface and burst at the top, it is an indication that cyclones will arrive within 1-2 days.
- When a flock of red coloured birds arrive from south and flies towards north it is an indication of impending cyclone 5 days later.
- When south wind blows, pomfrets and mackerel are got in plenty.
- When more white clouds are seen in the sky, than wind speed will be more on that particular day.
- The appearance of sea snake rolling itself in the waters is an indication of an impending cyclone 2-3 days later.
- The appearance of dragon flies in flocks moving from south to north direction is an indication of impending cyclone within two days.
- When butterflies move in groups over sea shore and sea surface it is an indication of cyclone approaching from the south west direction.
- Black cormorants (*Bangude hakki*) arriving in flocks ahead of rains is indicative of mackerel availability at sea.
- Appearance of White Sea gull (*Bili hakkī*) over sea surface is an indication of availability of anchovies.
- If foaming of water is observed near shore, it is an indication of impending cyclones.
- Cattle and goats are seen to break away from ropes and run towards the mountain side two days ahead of Tsunami.
- Flock of greyish black butterflies flying along the sea shore is indicative of oncoming rains within a week.
- When the waters near the shore becomes black, it is an indication of impending cyclones and when the water near the shore turns red, it is an indication of impending rains.
- When White Sea gulls flies away from the rocks at sea towards land, it is an indication of impending cyclones.
- When wind blows from north, more fishes are got. When wind blows from south, fishes aggregate into shoals.
- When wind blows in one direction only, less availability of fishes occurs.
- When wind blows from north, fish is available in plenty and when wind blows from the south, fish availability is less.
- When wind blows from sea towards land, the sea becomes silent and fishermen do not experience any problems in fishing.

## **Maharashtra**

- When the Sun is encircled by a kind of ring which is locally called as “*Vedha*” in Marathi, it is an indication of impending storms.
- Incidence of turbidity of near shore waters is an indication of impending storm.
- When the sea water gives a greenish tinge of colour, it indicates more fish availability.
- Turbidity at sea indicates more fish availability and clear water indicates less fish availability.
- When wind blows towards west or north direction, it indicates more fish availability and when the wind blows towards the south, it indicates less fish availability.

## **Gujarat**

- Fish availability is decided based on water currents.
- With increasing rainfall, fish availability in near shore areas decreases.
- Higher wind speed results in less fish availability, when sea is rough fish catches are less.
- When wind blows from west towards shore, fish availability is more.
- When wind blows from south to north, sea becomes rough and it is an indication of an impending cyclone.
- Reef cod fishes are abundant during winter season especially on new moon nights.
  - On new moon days stars become faint which is an indication of high wind speed.
  - Gathering of birds over sea surface indicates fish availability in that region.
- During full moon period more catch of squids are obtained.
- More fish availability is obtained with increase in temperature.
- Fishers predict the arrival of cyclone by observing peculiar circular movements of birds over the sea surface which thereafter moves towards the sky.

## **Kerala**

- If the current flows from the northern direction, it is an indication of less fish abundance and if the current flow is from the southern direction more fish will be available.
- When the wind blows from the sea side more fish is available and when the wind blows from the land side, less fish is available.

- Very clear water indicates less fish abundance.
- Fish abundance is high when currents are low.
- With rising temperature fishes move to deeper waters.
- If heavy rains are followed by calmer days, than incidence of small pelagic fish catch would be more.

### **Andhra Pradesh**

- Diverse catch of small pelagics, results with incidence of high salinity/decreasing rainfall.
- Wind blowing from north-east direction favours tuna catch.
- Change in water colour coupled with decreasing transparency caused by upwelling results in more catch of small and large pelagics.
- Unidirectional flow of surface currents and wind leads to good pelagic catch.
- Decreasing temperature, moderate sea state and north-east wind favours tuna catch in the months from October – February.
- Increase in catch of crustacean and cephalopod resources are observed with an increase in temperature.
- Inadvertent intrusion of jelly fishes into the coastal waters during summer months results in reduced catch rates of commercially important marine fin fishes and shell fishes.

### **Tamil Nadu**

- When up and down movement of sea water is more, it indicates less fish availability.
- Increased catch of squids is obtained during the summer months.
- During new moon period (*Amavasi*) more fish catches are obtained.
- During full moon (*Pournami*) fish catches are less.
- Bad smell at sea indicates no fish catch.
- When the wind blows from the southern direction during the month of April, fishermen get good fish catch.
- Coastal upwelling brings very good fish catches.
- During the months of October to November, when wind blows from the northern direction, good catches of fish will be obtained.

### **West Bengal**

- Increase in catch of clupeids and mackerel is observed with an increase in temperature.

## **Odisha**

- Increase in catch of clupeids and mackerel is observed with an increase in temperature.

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### Introduction

Ecosystem modelling studies are important concerning its vital role in determining the primary, secondary and tertiary productivity over the coastal as well as open oceanic domains. Two decades back, major limitation in these studies was the lack of high resolution oceanographic as well as meteorological data. Hence most of the studies were limited in regional scale because of the large scale collection of *in-situ* data sets are highly expensive and tedious. The advent of satellite oceanography during 1990's helps us to reasonably resolve the major limitation concerning the availability of data sets in the global domain. Since then extensive use of satellite oceanographic products were incorporated in the major oceanographic, meteorological as well as ecosystem studies. In the climate change scenario, these data are also being effectively utilised to resolve many issues in the climate related studies. In this tutorial note, we tried to give an insight to some of the major geophysical data products derived from satellite remote sensing techniques that are commonly used in the ecosystem studies and also to familiarise a major data provider named 'Asia Pacific Data Research Centre (APDRC)'. Basic geophysical data products and Tools, Software and Languages commonly used for analysis are listed in Table 1.

Table 1: List of basic satellite data products and Tools/Software/Languages commonly used for analysis.

| Basic Geophysical Data Products |           |               | Tools/Softwares/Languages |         |               |
|---------------------------------|-----------|---------------|---------------------------|---------|---------------|
| SST                             | SALINITY  | SLA           | FORTRAN                   | C & C++ | R             |
| WIND                            | CURRENTS  | PRECIPITATION | GRAPHER                   | SURFER  | SNAP          |
| AEROSOL                         | HEAT FLUX |               | ORIGIN                    | ODV     | SeaDAS        |
| BIO-OPTICAL PROPERTIES          |           |               | PYTHON                    | IDL     | MATLAB FERRET |
| CHLOROPHYLL-A                   |           |               | GRADS                     | PRIMER  |               |
|                                 |           |               | Arc GIS                   | Q-GIS   |               |

## **Product Levels**

In general, satellite data products are processed at varying levels. The National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) defines these levels as ranging from Level 0 to Level 4. Level 0 represents raw data, while Level 4 data have had the greatest amount of processing applied (Source: Ocean Colour Web).

### **Level 0**

Level 0 data are unprocessed instrument/payload data at full resolution. Any artefacts of the communication (e.g. synchronization frames, communication headers) of these data from the spacecraft to the ground station have been removed. These data are the rawest format available, and are only provided for a few of the missions that we support.

### **Level 1A**

Level 1A data are reconstructed, unprocessed instrument data at full resolution, time-referenced and annotated with ancillary information including radiometric and geometric calibration coefficients and georeferencing parameters computed and appended but not applied to the Level 0 data.

### **Level 1B**

Level 1B data are Level 1A data that have had instrument/radiometric calibrations applied.

### **Level 2**

Level 2 data consist of derived geophysical variables at the same resolution as the source Level 1 data. These variables are grouped into a few product suites (e.g. OC [ocean colour], SST, and SST4 for MODIS).

### **Level 3**

Level 3 data are derived geophysical variables that have been aggregated/projected onto a well-defined spatial grid over a well-defined time period. We archive two types of Level 3 data.

#### **Binned**

Each Level 3 binned data product consists of the accumulated data for all L2 products in a product suite, for the specified instrument and resolution, corresponding to a period of time (e.g. daily, 8 days, monthly, etc.) and stored in a global, nearly equal-area, integerized sinusoidal grid.

#### **Mapped**

The Level 3 Standard Mapped Image (SMI) products are created from the corresponding Level 3 binned products. A colour look-up table is also provided in each file that may be used to generate an image from the data.

### **Level 4**

Level 4 data are model output or results from analyses of lower level data (e.g.,

variables derived from multiple measurements). Ocean Primary Productivity is a good example of a Level 4 product.

### Data Access

There are different websites which provide various geophysical data products and that are offered either freely accessible or payment basis. Here we introduce three websites (Figure 1) named as Ocean Colour Web, GIOVANNI both are being maintained by NASA and Asia Pacific Data Research Centre (APDRC) website by International Pacific Research Centre (IPRC). GIOVANNI is an acronym for the Goddard Earth Sciences Data and Information Services Centre (GES-DISC) Interactive Online Visualization AND aNalysis Infrastructure. The first two are specially dedicated for ocean colour data products and the latter provides all available data products.

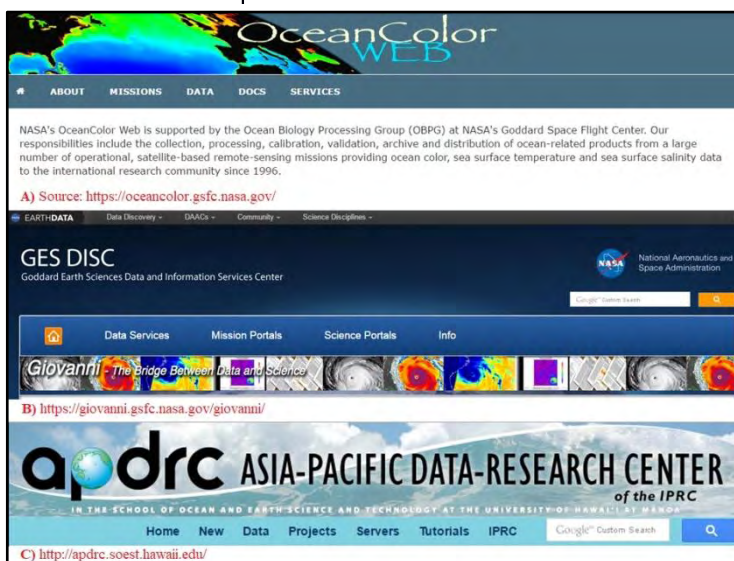


Figure 1: Screen shots of A) Ocean Colour Web B) GIOVANNI and C) APDRC website.

The access of data in different formats and their web based analysis using APDRC website are briefly explained in the following sections. The home page of the website has filters to select the desired data sets for ocean, atmosphere, terrestrial etc. which are shown in the left panel and the available data sets are displayed alphabetically in the right panel according to the selection of filters (Figure 2). We have selected 'Chlorophyll-a' as a representative variable to demonstrate the access and process the data. To access Chlorophyll-a data, filter should be selected as 'All Disciplines' in the sub-section of 'Data'. Then 'Chlorophyll-a' data from MODIS sensor can be seen in the right panel of the



website (Figure 3). There are different options to access the data that can be seen adjacent to the variable name as LAS, LAS8, OPeNDAP etc. Select the LAS option to go for the next step (a new TAB will be opened automatically in this step) where all the available data either in monthly or weekly temporal scale will be displayed (Figure 4A). A single click on desired temporal scale is required to go for next step.

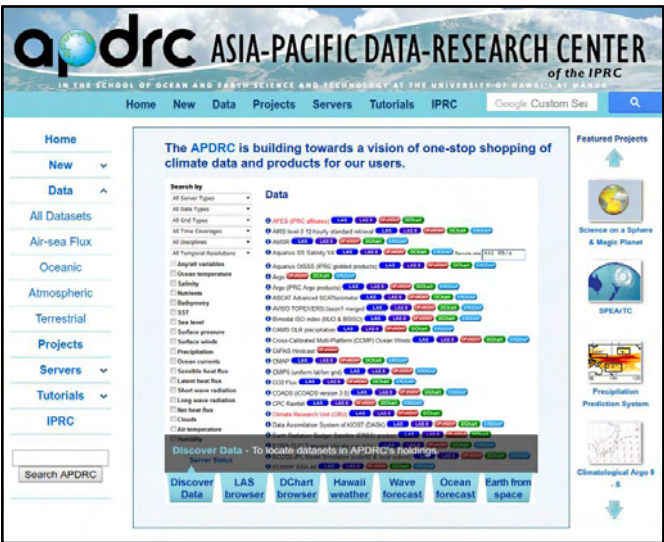


Figure 2. Home page of APDRC website.



Figure 3. Selection of MODIS Chlorophyll-a data highlighted in red colour.

After the selection of 'monthly/weekly' data, the same window will be redirected



to next step where the available variable names will be shown as in Figure 4B (here it is 'Chlorophyll-a concentration').



Figure 4. Screen shots of webpage opened in a new TAB where options A) To select Monthly/Weekly data B) To select Chlorophyll-a data.

The user has to click on 'Next' at the right end of the same page as shown in the Figure 4B. Then the page will be redirected to the final step to select the grid and format of the data (Figure 5). The options 'Select view', 'Select output' and 'Select region' (upper side as shown in Figure 5) has to be changed in order to access the data in the desired format. The option 'Select view' may be changed to 'Time-series' or 'Hovmoller diagram' as per the requirement of the user to get long term time series plots and latitude/longitude averaged variability with time. The required period can also be applied in this step. At the end, a final click on 'Next' (Figure 5) is required to generate the map (Figure 6) or data in different format (ASCII or NetCDF) as shown in Figure 7. Here, the user will be redirected

in to a new window with a link to download the data or save the image to the desired directory.

**APDCR LAS7 for public**

OPeNDAP/E-TDS/\_THREDDS/ Index | Search:

---

**Datasets > APDCR Public+Access Products > Oceanwatch = MODIS Aqua - Monthly Ocean Color Variable(s): Chlorophyll-a Concentration**

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Select your desired view (geometry of output) and output (type of product).  
Then set the 4-D region (lon-lat-depth-time) and any additional constraints.

[Help](#)

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**Select view:** Longitude-Latitude map (xy) ▾

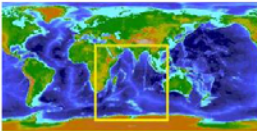
**Select output:** Color plot ▾

**Select region:** Indian Ocean ▾   
[Use the interactive map](#) [Help](#)

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**Help** ☒ **Reset**

30 N  
20 E 120 E  
75 S



< >

**Zoom** ☒ **Zoom** ▾

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**Select time:** Jul | 2002 ▾

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**Select options:**

- ☒ Evaluate expression
- ☒ Interpolate normal to plot
- ☒ Image format
- ☒ Plot size
- ☒ Show reference map
- ☒ Show graticule
- ☒ Margins

Off ▾  
Default ▾  
default ▾  
Default ▾  
Default ▾

Figure 5. Final step to select grid, format of data, period etc.

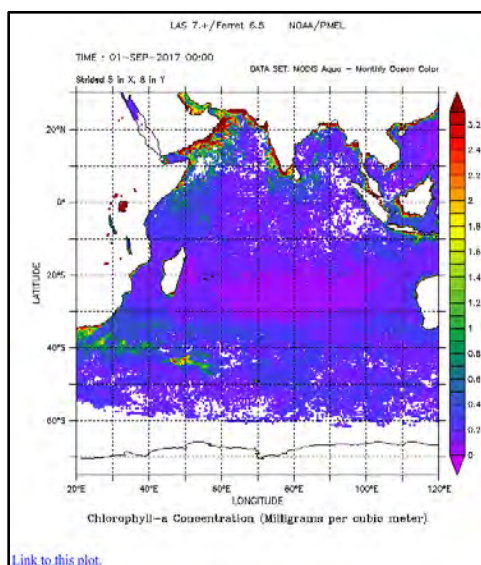


Figure 6. Output data generated as 'map' and link (see left bottom side) to download it as image.



Figure 7. Option to download output data in 'NetCDF' format.

## Conclusion

The geo-physical data sets available in open source data bases can be effectively utilised to resolve research problems related to climate change studies. Often we lack long term time series data sets to study climate change related impacts in marine ecosystems. Collection of *in-situ* information is tedious and expensive. Most of the time it is practically impossible to collect such data. In this chapter, we have given an insight to major oceanographic and climate related variables which will facilitate research related to climate change studies.

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NASA- Ocean Colour (<https://oceancolor.gsfc.nasa.gov/>)

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### Introduction

Over the last two decades several studies have been carried out over the North Indian Ocean (NIO) by explaining the impact of extreme oceanographic events on the general hydrodynamic and thermodynamic characteristics of the Arabian Sea and Bay of Bengal (Tourre and White, 1995; Behera et al., 2000; Bakun et al., 2015). Some of these investigations are extended to the vulnerability studies of the major fishery along the Indian coastline with respect to the present scenario of enhanced frequency of occurrence of extreme climatic events such as El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) (Krishna Kumar et al 2008, Thara. 2012). These climatic fluctuations may be responsible for the inter-annual variability in abundance of fish populations. Highly mobile, plankton-based food chain and short life spans make the pelagic fishes predominantly sensitive to environmental forcing. Concerning the importance of marine fishery resources as a major source of income, so the influence of these extreme climatic events on the ecosystem productivity and fishery production should be studied well (Thara, 2012). Based on the above baseline information, the present tutorial is try to elucidate the influence of extreme events on Indian Oil Sardine fishery along the south-west coast of India. Rather than the detailed description of one to one relationship between the extreme oceanographic events and major fishery, this tutorial is mainly intended to provide some hints on the variability observed in the trend of Oil Sardine landings along the south-west coast of India during a decade with more number of extreme events. The period selected for this study is from 1990 to 2015, in which the two decades from 1990 to 2015 is characterized by the occurrence of more number of ENSO and IOD.

## Data and Methods

Concerning the importance of temperature and primary productivity induced by upwelling in determining the annual pelagic fishery production along the shelf waters, an attempt has been made to understand the inter-annual variability of Coastal Upwelling Index (CUI) and Mixed layer Temperature (MLT) along the south-west coast of India. The study is also extended to understand the specific influence of extreme events on the profound variability observed in the MLT and CUI during the IOD and ENSO years. A correlation analysis between the CUI and Oil Sardine fishery is also included in this study. Ekman mass transport derived from the alongshore component of wind along the south-west coast of India is used as Coastal Upwelling Index (CUI) and the calculation of CUI is followed by Shah et al., 2015. ERS, QuickSCAT and ASCAT wind products were used for the calculation of coastal upwelling Index along the south-west coast of India. The fish landings data for Indian Oil sardine was collected from Central Marine Fisheries Research Institute. MLT is calculated from the potential temperature profile provided by Simple Ocean Data Assimilation (SODA).

## Results and Discussion

### Indian Ocean Dipole and El Niño Southern Oscillation (ENSO)

Table 1 represents the list of IOD, El Niño and La Niña years during 1990 to 2015. From the Table 1, it was evident that during the entire study period the first decade from 1991 to 2000 was experienced by more number of IOD events. During this decade, out of the five IOD events occurred, two of them are Strong positive IOD years (1994, 1997) and the rests are strong negative IOD years (1992, 1996 and 1998). Year 1997 was peculiar by the co-occurrence of strong IOD and strong El Nino. Another distinctiveness of the first decade is that all the years from 1991 to 2000 are characterised by the occurrence of either an IOD (positive or negative) event or an ENSO (El Niño or La Niña) event.

Second decade (from 2001 to 2010) during the study period is the more occurrence of ENSO events and rarest occurrence of IOD events compared to the first decade from 1991 to 2000. After 2010. The years from 2014 to 2016 are strongest El Niño years and 2015 is a strong positive IOD year.

Table 1: List of IOD and ENSO events during 1990 to 2016

| Positive IOD events | Negative IOD events | El Niño events | La Niña events |
|---------------------|---------------------|----------------|----------------|
| 1994                | 1992                | 1991-1992      | 1995-1996      |
| 1997                | 1996                | 1992-1993      | 1998-1999**    |

|             |      |            |             |
|-------------|------|------------|-------------|
| <b>2006</b> | 1998 | 1994-1995  | 1999-2000   |
| <b>2012</b> | 2010 | 1997-1998* | 2000-2001   |
| <b>2015</b> | 2016 | 2002-2003  | 2007-2008** |
|             |      | 2004-2005  | 2010-2011   |
|             |      | 2006-2007  |             |
|             |      | 2014-2016* |             |

\* represents strong El- Niño year; \*\*represents strong La Niña year.

### Inter- annual variability of Mixed Layer Temperature (MLT)

Previous studies revealed the influence of temperature on fish spawning behavior and every fish stocks have a particular temperature choice with a temporal cycle and any change in this temperature pattern significantly influences the gonadal ripening of the fish. Since the influence of ENSO and IOD events are predominant on temperature during the winter season, a two month average of MLT during November and December is used to understand the inter-annual variability of temperature along the shelf waters of south-west coast of India.

Analysis of **Figure 1** revealed that the highest ever recorded mixed layer temperature along the south-west coast of India from 1990 to 2015 is during 1997 and it is a strong positive IOD year co-occurred with El Niño. The lowest temperature occurred along the south-west coast of India is during 1999. Analysis also revealed that the co-occurrence of El Niño and positive IOD events (1994, 1997, 2006 and 2015) significantly increases the winter temperature along the shelf waters of south-west coast of India compared to previous years. Positive IOD (2012) and strong La Nina (2010) alone decreases the temperature along the south-west coast of India.

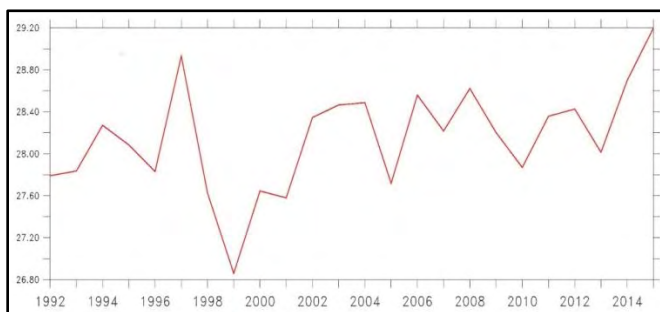


Figure 1: Inter-annual variability of Mixed Layer Temperature (°C) along the south-west coast of India from 1992 to 2015[November-December averaged].

### Inter-annual variability of Coastal Upwelling Index (CUI)

Since the south-west coast of India was characterized by upwelling during the summer monsoon, CUI averaged over June to September is used in this study to understand the inter-annual variability of upwelling along the south-west coast of India. Figure 2 represents the CUI variability along the shelf waters during the study period from 1990 to 2015. From Figure it was evident, upwelling along the south-west coast of India is considerably lower during 1992 to 1999 compared to the rest of the study period and this was a decade with more number of extreme oceanographic events. During the entire study period stronger upwelling due to the Ekman mass transport was observed during 2000 to 2008. During the strong positive IOD years 1994 and 1997 upwelling along the south-west coast of India considerably diminishes compared to the previous years. Analysis of Figure 2 also revealed that during the entire study period the highest recorded upwelling is during 2000 and minimum value of CUI was observed during 1998 and it was a strong La Niña year.

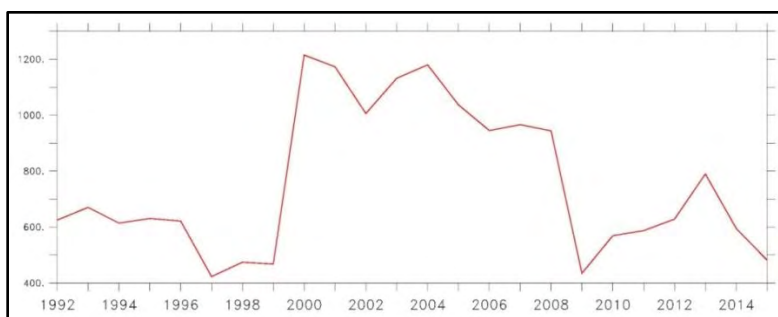


Figure 2: Inter-annual variability of Coastal Upwelling Index along the south-west coast of India from 1992 to 2015 [June-September averaged]. Ekman mass transport (kg/m/s) is used as Coastal Upwelling Index.

### Inter-annual variability of trend in Indian Oil Sardine landings along the south-west coast of India

Figure 3 represents annual average Indian Oil Sardine landings along the south-west coast of India from 1985 to 2016. Considerable decrease in Oil Sardine landing was observed along the south-west coast of India during 1991 to 1999 and this was a decade with more number of climatic events. Also this decade was characterized with more number of Indian Dipole events compared with the other decade.

Analysis of Coastal Upwelling Index (CUI) also showed the declining trend in upwelling along the south-west coast of India during this decade. During the entire study period lowest catch was recorded in 1994 and it was a positive IOD



year. From 1995 onwards an increase in trend in Oil sardine landings was observed along the south-west coast of India and a maximum catch was observed during 2012. After 2014 a decline in Oil Sardine landing was initiated along the south-west coast. The decade from 1991 to 2000 was a strong IOD era and the years from 2001 to 2010 characterizes more number of ENSO events.

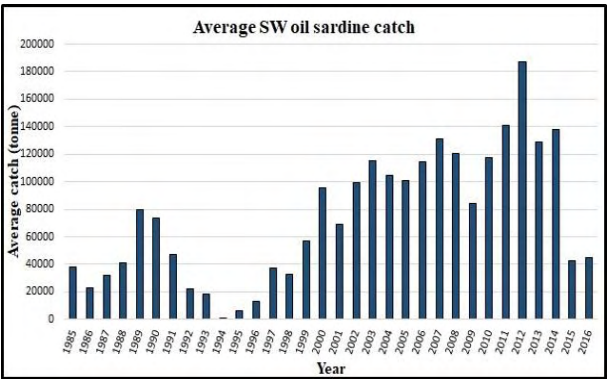


Figure 3: inter-annual variability of Oil Sardine landings along the south-west coast of India from 1985 to 2016.

Hence the overall analysis of trend observed in Oil Sardine catch hints the adverse influence of IOD events on Oil Sardine fishery along the south-west coast of India.

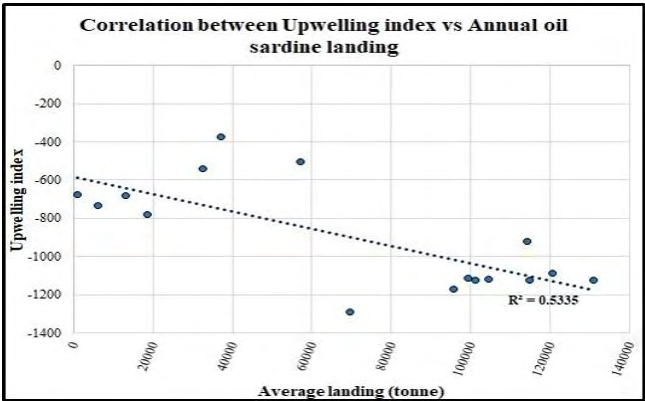


Figure 4: Correlation analysis between CUI and Annual Oil sardine landings along the south-west coast of India. Simple Correlation analysis between CUI and Oil Sardine catch also showed a significant positive correlation along the south-west coast of India (Figure 4).

### Conclusion



The objective of the present tutorial is intended to provide some hints on the interaction of extreme climatic events and coastal dynamics on Indian Oil Sardine fishery along the south-west coast of India. The results of the analyses of Coastal Upwelling Index and Mixed Layer Temperature revealed that upwelling significantly diminishes and a corresponding increase in Mixed Layer Temperature was observed along the south-west coast of India during the positive IOD years. The study also showed some insights on the adverse effects of IOD events on the Oil Sardine fishery along the south-west coast of India.

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The recruitment of most marine fish is highly variable and most often it may not be visible to have an evident relation with the abundance of the parental stock (spawning stock biomass). Among other factors a major reason for this is the high and variable rates of mortality of the young ones (juvenile mortality) in the early life stages, which are assumed to be highly influenced by environmental processes. In particular, the larvae of pelagic fishes are highly sensitive to environmental changes and larval mortality rate will affect recruitment of fish into the fishery thus affecting their biomass and availability in the catch.

Being environment driven, effect of climate change on fish stock as well as catch has to be examined through appropriate modelling techniques. Depending on the biological features (recruitment size/age, maturity) it is wise to include lagged effects environmental variables in the model describing the fishery. More than one environmental variable can be included to evaluate their relationship with the variables of interest such as fish catch, stock biomass and catch rates or Landings Per Unit Effort (LPUE). While modelling the fishery incorporating environmental variables it is good to start with simple models with only one environmental variable and when it is found significant more than one variable or its combinations can be included in the model. In order to examine regional or seasonal effects we may attempt by including seasonal and regional data in the modelling exercise. In the model, Landings per unit effort (LPUE) can be response variables while fishing effort and environmental variables are explanatory variables. When we attempt modelling with a set of variables both response as well as auxiliary care should be taken to avoid including variables having collinearity. All data series may be tested for normality (Quantile-Quantile plots -QQ-plots) and collinearity (pairs plots, Zuur et al. 2010). Separate

model/analysis for regions is necessary in order to account for the different environmental conditions and spatial independence among regions.

### Model for Recruitment

A method generally used in fisheries to relate mature populations ( $S$ ) with the recruitment abundance ( $R$ ) at any given time  $t$ , was suggested by Ricker (1975), who proposed an exponential functional relationship of the following form between them.

$$R_t = S_t e^{a - b S_t}$$
$$y_t = \log\left(\frac{R_t}{S_t}\right) = a - b S_t + \epsilon_t$$

where  $a$  and  $b$  are describe population productivity at low density and capacity limited by density-dependence, respectively. If we assume log-normally distributed recruitment, then

Chen & Irvine (2001) extended the Ricker model (extended Ricker model) to include environmental variables as follows:

$$y_t = \log\left(\frac{R_t}{S_t}\right) = a - b S_t + \sum_i c_i Z_{i,t} + \epsilon_t$$

### Statistical models

To evaluate the influence of different environmental variables on the response variables some of the suitable statistical models are:

- Dynamic Factor Analysis (DFA)
- Generalised Least Squares (GLS)
- Time series models

Different analysis may reveal varying results and hence suitable model selection criteria have to be used before finalising the model. Suggested criteria are Akaike's information criterion (AIC), decision tree etc.

### Generalised Least Square Method

In linear least square method the model for the observed data  $Y$  in terms of the explanatory variables  $X$  is

$$Y = X\beta + \varepsilon$$

where  $Y$  is the response vector,  $X$  is the explanatory variables matrix,  $\beta$  is the vector of coefficients and  $\varepsilon$  is the vector of random errors having mean vector zero and dispersion matrix  $\sigma^2 I$  where  $I$  is the identity matrix. That is the random errors are independent and identically distributed with constant variance. But in many situations this assumption is violated due to unequal variance of the error terms and also they may be correlated. This limits the use of linear least square method and the alternative approach in such situations is Generalized Least Square Method. In generalised least square the model for observed data  $Y$  in terms of the explanatory variables  $X$  is

$$Y = X\beta + \varepsilon$$

The error vector  $\varepsilon$  has mean vector zero and dispersion matrix  $\sigma^2 V$  where  $V$  is not an identity matrix. When  $V$  is diagonal with unequal values the errors are uncorrelated and when  $V$  is not diagonal the errors are correlated. In climate change related studies, we are interested in evaluating the influence of different climatic variables on fish yield. In the above model, the response vector can be the fish resources yield and the explanatory variables are the climate variables. In generalised least square model the estimate of parameter vector  $\beta$  is given as follows.

$$\beta = (X'V^{-1}X)^{-1}X'V^{-1}y$$

### Dynamic Factor Analysis

Dynamic factor analysis is a recent development in multivariate time series analysis where the objective is to estimate underlying common trends in a set of time series data and also to extract the influence of another set of explanatory time series towards the common trends. The mathematical expression of the model is

$$y_t = A \times z_t + B \times x_t + \varepsilon_t$$

$$z_t = z_{t-1} + e_t$$

Where,  $y_t$  is a vector time series with  $k$  time series components,  $z_t$  is the vector time series with  $m$  components representing the common trends ( $m < k$ ),  $A$  is a matrix of order  $k \times m$  (termed as factor loadings),  $x_t$  represents the explanatory variables time series vector with  $r$  components,  $B$  is another regression parameter matrix of order  $k \times r$  and  $\varepsilon_t$  and  $e_t$  are vectors representing the noise/error components. For climate change studies vector  $y_t$  is composed of LPUE time series of fishery resources yield and the explanatory variable time series vector  $x_t$  is composed of time series data on climate variables.

### Multivariate time series models models.

Values observed over a period of time can be treated as a time series process generated by a mechanism and can be studied in time series context to see the trend, inter-relations, periodicity etc., using time series techniques. By exploiting the inter-relations between time series sequences models can be developed to forecast future values with more precision. The most popular class of stationary stochastic model used for time series modeling is ARIMA model (Auto Regressive Integrated Moving Average model) introduced by Box and Jenkins (1976). This includes, autoregressive models, moving average models, random walk models, autoregressive moving average models, integrated models and seasonal models. In autoregressive (AR) models, the current value of a process is expressed as a linear aggregate of past values along with a random shock. The AR model of order  $p$ , denoted by  $AR(p)$ , is of the form

$$\tilde{z}_t = \phi_1 \tilde{z}_{t-1} + \phi_2 \tilde{z}_{t-2} + \dots + \phi_p \tilde{z}_{t-p} + \varepsilon_t$$

Using the back shift operator  $B$ , the  $AR(p)$  model can be written as

$$\phi(B)\tilde{z}_t = \varepsilon_t$$

Where

$$\begin{aligned} \tilde{z}_t &= \phi_1 \tilde{z}_{t-1} + \phi_2 \tilde{z}_{t-2} + \dots + \phi_p \tilde{z}_{t-p} + \varepsilon_t \\ \phi(B) &= 1 - \phi_1 B - \phi_2 B^2 - \dots - \phi_p B^p \end{aligned}$$

is the characteristic polynomial of the AR(p) model. In moving average (MA) models, the current value of a process is expressed as a linear combination of a finite number of previous random shocks. The MA model of order  $q$ , denoted by MA( $q$ ), has the mathematical form

$$\begin{aligned}\tilde{z}_t &= \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \dots - \theta_q \varepsilon_{t-q} \\ &= (1 - \theta_1 B - \theta_2 B^2 - \dots - \theta_q B^q) \varepsilon_t \\ &= \theta(B) \varepsilon_t\end{aligned}$$

The combined model is the Auto Regressive Moving Average model denoted by ARMA(p,q) having the following mathematical expression

$$\begin{aligned}\tilde{z}_t - \phi_1 \tilde{z}_{t-1} - \phi_2 \tilde{z}_{t-2} - \dots - \phi_p \tilde{z}_{t-p} &= \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \dots - \theta_q \varepsilon_{t-q} \\ (1 - \phi_1 B - \phi_2 B^2 - \dots - \phi_p B^p) \tilde{z}_t &= (1 - \theta_1 B - \theta_2 B^2 - \dots - \theta_q B^q) \varepsilon_t \\ \phi(B) \tilde{z}_t &= \theta(B) \varepsilon_t\end{aligned}$$

Each of the above models has modified versions to incorporate explanatory time series variables into the model. Similarly there are multivariate versions for each the models where in more than one time series are modeled simultaneously known as vector time series models. For example the model with the addition of an explanatory variable is known as ARX model and its expression will be as follows.

$$\phi(B) \tilde{Z}_t = \beta_0 x_t + \beta_1 x_{t-1} + \dots + \beta_r x_{t-r} + \varepsilon_t$$

The above model is capable of extracting the influence of an explanatory variable for different lags such as climate on the response variable which can be the fish yield.

## Rejuvenation of the Traditional Pokkali Farming System through Integrated Paddy- Shrimp Fin Fish Farming

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### Introduction

Pokkali farming is a typical farming system in which paddy and shrimp cultures are alternatively done in the same field (S. M. Pillai 1999). The biomass residues of paddy crop forms feed for shrimps and residues of shrimp farming forms fertilizer for the paddy. There are no external inputs used in this farming as both the cultures are mutually compensating and the soil is nutrient rich as it is carried by river flows and deposited in the Pokkali fields which are located in the coastal areas (George 1968). Pokkali farms are spread mainly in the coastal areas of Ernakulam and in some parts of Thrissur and Alappuzha districts of Kerala (Panikkar, N. K 1937).

Pokkali farming is purely organic as the farmers do not use any chemicals because they have to start shrimp farming in the next season. Pokkali paddy and prawn possess a characteristic taste since no chemical inputs are used as well as the rich peaty soil in pokkali fields also imparts good taste to the pokkali rice and shrimp (Purushan, K. S. 1996). Since rice is the most important food crop of the world (Cantrell and Reeves 2002) conservation of naturally organic varieties needs special attention. Pokkali paddy received geographical Indication (GI) and a logo during 2007 and plant genome community saviour award during 2011 from Govt. of India.

Lee et al. 2003 reported that very few Rice varieties possess ability to resist salinity during its growth phase. Pokkali paddy requires less than 1 ppt salinity for its germination. However once germinated and grown, it can sustain salinities upto 5 ppt. Hence the planting season coincides with onset of monsoon in June first week during which the salinity of the soil gets washed off in runoff water. The growth period is 120 days and during this

phase, the salinity increases up to 4 ppt. The pokkali paddy grains are resistant to decay in submerged conditions.

The field preparations starts after April 14<sup>th</sup> and paddy seeding would be done after 3 or 4 monsoon showers in the first week of June. The harvesting is done in the first week of October. Shrimp farming in pokkali fields require license. The license period is for 5 months starting from November middle to April middle. It's a tradition in pokkali farming tracts that fishermen (landless) can catch fish from pokkali fields except during this license period irrespective of the ownership of the field. This tradition is a classic example of how our ancestors were concerned about the livelihood of all the classes in the society.

This paddy variety is promising in the context of climate change where the sea water level is raising leading to intrusion of salinity in fresh water systems and paddy fields. Un-predictable rain and associated flood is also yet another consequence of climate change. Pokkali paddy can very well sustain flood as well by growing above flood waters up to a height of 1.5 metres whereas the ordinary paddy can grow only up to 0.9±0.2 m. Pokkali can sustain in this situation also as it has flood resistant properties as mentioned. Hence the pokkali germplasm needs conservation as a promising crop for saline areas in the future years.

There were more than 25,000 ha under Pokkali cultivation in Kerala 10-15 years back, which has come down to 5,000 ha currently and the cultivation is being done only in an area of less than 610 ha (Table 1).

Table.1 Status of pokkali paddy fields and production in Kerala

| District  | Available Area (ha) | Presently Cultivating area (ha) | Production (ha) |
|-----------|---------------------|---------------------------------|-----------------|
| Ernakulam | 4000                | 610                             | 929.64 ton      |
| Alappuzha | 3000                | -                               | -               |
| Thrissur  | 2000                | -                               | -               |

#### Issues identified in the Pokkali farming system

- Lack of machinery for land preparation as the Pokkali fields are marshy to cause sinking of the land preparation machinery like tractors and power tillers. Even now Pokkali lands are prepared by



manual labour using long handled spades. Labour in Kerala is costly and scarce which contributes to increased production costs.

- Lack of machinery for harvesting the paddy which is in a state of *floating* in water at the time of harvesting. Manual harvesting involves drudgery as the labourers need to work in standing water.
- Low productivity of Pokkali paddy in the range of 1.5 MT/ha for local varieties and only 2.5 MT/ha for improved varieties in comparison to the productivity of 5.2 MT/ha for hybrid paddy varieties commonly cultivated elsewhere.
- Set back to the shrimp farming due to WSS (White spot syndrome) virus disease, which is a global issue. Most of the loss in paddy crop in the previous season were compensated by the remunerative shrimp farming in the subsequent season till the WSSV incidence.
- Pollution from the industries located upstream of pokkali fields.
- Though quality and taste of the pokkali paddy are its attractions, there is no premium market for the paddy and shrimp grown in pokkali fields.
- This farming system is largely depending on climate, *i.e* onset of monsoon and tidal fluctuations.

Many farmers are traditionally continuing pokkali farming despite all these constraints due to cultural and emotional attachments to the farming and to continue the tradition.

### **Challenges**

The indigenous fishermen of this region have the traditional right to enter these farmers' fields and catch wild fish and shrimp as livelihood means prior to and during the paddy cultivation period. Land holding farmers get exclusive ownership and license to their field solely for five months during shrimp farming. At the end of each year's license period the farmers open up the fields again for the local fisherfolk for their livelihood. Due to this special agreement between farmers and fisherfolk any intervention in this farming system is challenging. But at the same time a strong intervention is required since widespread attack of viral disease on shrimp, labour shortage, lack of machinery, water pollution, low market price, erratic monsoon, saline intrusion, unpredicted floods etc. is compelling the farmers to discontinue this farming system.

The main objective of the present work is to develop and introduce a new package of practice to augment income from unit area of Pokkali field by

integrating high density cage culture of high value candidate fin fishes such as pearl spot Asian sea bass and mullet along with shrimp in the pokkali farming system without disturbing the traditional farming system.

### Area description, materials, methods and techniques employed

#### Integrated cage culture of finfish

A detailed survey was conducted and selected pokkali fields located at Kadamakkudy, Ezhikkara, Pizhala and Nayarambalam for the present study measuring in size varying from 4.5 acres to 50 acres respectively (Table 2).

Table 2. Details of farmers with farming area and species of finfishes cultured in Pokkali farming systems

|    | Pokkali farmers   | Area (Acre) | Species Stocked                     |
|----|---|-------------|-------------------------------------|
| 1. | Pushpangathan K.A Karammal H<br>Kadamakkudy, Pizhala          | 6.0         | Mullet, Pearl spot<br>Asian Seabass |
| 2. | Murali P.R Putheth H<br>Kadamakkudy Pizhala                   | 6.75        | Mullet, Pearl spot                  |
| 3. | Vincent V.A Valiyaparambil H<br>Kadamakkudy Pizhala PO        | 16.0        | Mullet, Pearl spot<br>Asian Seabass |
| 4. | Vinod Kumar D.V<br>Devaswamparambil H<br>Kadamakkudy, Pizhala | 7.0         | Mullet, Pearl spot<br>Asian Seabass |
| 5. | A.R. Saigal, Anjil H Ezhikkara,<br>Vypeen                     | 3.5         | Mullet, Pearl spot<br>Asian Seabass |
| 6. | Shyam Sunder P.R. Pallathupady<br>H Nayarambalam, Vypeen      | 50.0        | Mullet, Pearl spot<br>Asian Seabass |
| 7. | K.K. Ramakrishnan Kallarakkal H<br>Pizhala                    | 4.5         | Mullet, Pearl spot, Asian Seabass   |

In order to initiate integrated farming of fin fishes cage fish culture method was adopted. The vacant sluice pits and channels in the pokkali fields area was selected for the integrated cage fish culture along with paddy. The sluice pits and channels in their Pokkali fields were de-silted and cleaned to ensure minimum 2m water depth in the sites wherever required. Mullet (*Mugil cephalus*), Asian Sea bass (*Lates calcarifer*) and Pearl spot (*Etroplus suratensis*) were selected as the candidate species for the integrated farming. Due to the erratic rains received during June of 2014, many of the pokkali seeds sown were washed away by runoff water and in 2014 less than 200 ha were under active farming.

### Nursery rearing of mullet (*Mugil cephalus*)

Mullet seeds are generally caught from the sea shore during the onset of monsoon by traditional fisherman using cast net. The length range of wild caught mullet was 1- 2 cm and weight range was 150-400 mg. Fry's of these size are not ideal to stock in cages directly and therefor nursery rearing is essential to rear the fish in to fingerling size (above 8cm) which is ideal for stocking in cages for integrated farming. Mullet fry's (3000) acclimatized and stocked in the netlonhappas (1.2m x 1.2mx1.2m size) fixed using bamboo poles in the main channel of the Pokkali field. The fishes were fed using floating (500 micron, 700 micron) and slow sinking commercial feeds (1mm) with high protein (>40%) and fat content (>8%) for 30 days.

### Grow out culture in cages

Grow out culture was done in rectangular floating cage units. The cages were fabricated using HDPE nets and PVC pipes. HDPE nets of 12mm mesh (0.5mm thickness) and 16mm (1mm thickness) were selected for cage fabrication. The cage floating unit was fabricated using 90 mm PVC pipes. Cage sinkers were fabricated using 32mm PVC pipes filled with sand. Fingerling size mullet, pearl spot and Asian seabass was stocked separately in each cage. Stocking density was 30/m<sup>3</sup>, 40/m<sup>3</sup> and 30 m<sup>3</sup> respectively.

### Feeding

Commercially available formulated floating pellet feed of 2mm size containing 32 % protein and 4 % fat was used for feeding mullet whereas, Institute developed feed "Pearl plus" was used for pearl spot culture. This feed contains 47% protein, 6% fat and also other essential nutrients such as vitamins, minerals, etc., Proximate composition of Pearl plus larval and grow out feed are given in Table 3.

Table 3. Proximate composition of "Pearl plus" larval and grow out feed

| Sample name              | % dry matter | % moisture | % crude protein | % crude fat | % crude ash | % crude fibre | % acid insoluble ash | % nitrogen free extract |
|--------------------------|--------------|------------|-----------------|-------------|-------------|---------------|----------------------|-------------------------|
| Pearl plus grow out feed | 93.63        | 6.37       | 38.36           | 4.33        | 11.46       | 3.45          | 4.61                 | 36.04                   |
| Pearl plus               | 93.71        | 6.29       | 44.71           | 6.90        | 14.54       | 4.09          | 5.37                 | 23.47                   |

Pearl spot fingerlings were fed Pearl plus PS3 (1000  $\mu$ m), PS 4 (1.4 mm) and juveniles fed PS5 (2 mm). Asian Seabass were fed with 1.2 mm floating pellet feed and 2 mm floating pellet during dawn and dusk.

### **Grow out culture in open fields**

Mullet seeds were reared in cages during the paddy farming season and released in to the Pokkali fields after the license period (November 15). Formulated floating feed (2mm) were fed twice a day at fixed points in the four corners of the field.

### **Water quality testing and Analysis**

Water samples were collected fortnightly from the pokkali field and nearby creek and water during the farming period. 15 Hydrographical parameters varying from atmospheric temperature to ammonia content in the pond water were analyzed using water samples collected from the different aqua farms in Kadamakkudy, Pizhala, Ezhikkara and the creek situated in Kadamakkudi. An average fourteen day sampling interval protocol were followed for the collection of water samples. The samples were usually collected during the morning hours. Physical parameters such as temperature and salinity were recorded on the sampling site itself using digital analytical instruments. Fixation of dissolved oxygen was also carried out on site. Water samples were collected from both the inlet sluice entrance area and other different area of the farm as well. The collected water samples were stored in one L high density plastic dark bottles in duplicate. The samples were transported to the laboratory in ice box and stored in freezing temperature in the lab to maintain United States Environmental Protection Agency (1976) guidelines. Before the laboratory analysis the samples were thawed overnight. The physico-chemical and biological analysis were carried out following the APHA 1981 protocol in room temperature.

### **Results and discussion**

Significant variations in all the water quality indicators were obvious in the Pokkali farming system. Since the water in Pokkali fields are replaced daily with the creek water according to the tide, control over the water quality regulation was negligible in this farming system. Rain fall, tidal strength, river run off volume, etc., are the major critical factors which influenced the water quality in the system.

Among the various water quality indicators, pH of the Pokkali field ranged from 6.54 (June during monsoon) to 8.00 (February during summer). pH is always interdependent with other water quality parameters, such as carbon dioxide, alkalinity, and hardness. It can be toxic in itself at a certain level, and also known to influence the toxicity as well of hydrogen sulfide, cyanides, heavy metals, and ammonia (Klontz, 1993). According to Boyd, 1998 fresh water fish can tolerate wide variation in pH (6.5 - 9.0) whereas the tolerable pH range for euryhaline fish is usually lies between pH 7.5 and 8.5. Normally fish growth will be cease or it will die when pH rises above 11 or decrease below 4.0 (Lawson, 1995). Pearson correlation revealed (2-tailed) significant positive correlation ( $P < 0.05$  level) between the pH and salinity of the Pokkali fields (Table 1).

Table 1. Pearson Correlation of salinity and pH of the Pokkali fields

|          |                     | pH    | Salinity |
|----------|---------------------|-------|----------|
| pH       | Pearson Correlation | 1     | .467*    |
|          | Sig. (2-tailed)     |       | .025     |
|          | N                   | 23    | 23       |
| Salinity | Pearson Correlation | .467* | 1        |
|          | Sig. (2-tailed)     | .025  |          |
|          | N                   | 23    | 23       |

\*. Correlation is significant at the 0.05 level (2-tailed)

### Salinity

Salinity is the crucial water quality parameter in the Pokkali farming system wherein the species diversity and abundance was directly influenced. Salinity in the Pokkali fields varied significantly throughout the year (Table 2 & Fig 1). Average salinity in the Pokkali fields varied from 0.51 ppt (during July month) to 23.96 ppt (during May month). Reduction in salinity was observed during the onset of south west monsoon. Reduction is significant during these periods in all the fields (23.96 ppt to 3.29 ppt. This is essentially required to backwash the saline contents from Pokkali soil which is required to start the paddy cultivation. Sudden changes in water quality contents significantly affect the micro and macro flora exists in the system. This may reduce the bacterial and other parasites load in the system naturally.

Table 2. Salinity of Pokkali fields

| Sampling Time | Salinity (ppt) | Std. Deviation | Std. Error |
|---------------|----------------|----------------|------------|
| June 1        | 3.29           | 0.39           | 0.22       |
| June 15       | 1.37           | 0.15           | 0.09       |
| July 1        | 0.51           | 0.44           | 0.26       |
| July 15       | 0.28           | 0.24           | 0.14       |
| August 1      | 0.76           | 0.69           | 0.40       |
| August 15     | 0.55           | 0.47           | 0.27       |
| September 1   | 0.95           | 0.38           | 0.22       |
| September 15  | 1.18           | 0.28           | 0.16       |
| October 1     | 4.35           | 0.45           | 0.26       |
| November 1    | 6.04           | 0.05           | 0.03       |
| November 15   | 7.05           | 0.05           | 0.03       |
| December 1    | 7.33           | 0.31           | 0.18       |
| December 15   | 11.85          | 0.55           | 0.31       |
| January 1     | 13.89          | 0.40           | 0.23       |
| January 15    | 17.50          | 0.10           | 0.06       |
| February 1    | 19.08          | 0.13           | 0.08       |
| February 15   | 15.60          | 0.10           | 0.06       |
| March 1       | 16.23          | 0.46           | 0.27       |
| March 15      | 15.95          | 0.22           | 0.13       |
| April 1       | 18.33          | 0.38           | 0.22       |
| April 15      | 20.98          | 0.43           | 0.25       |
| May 1         | 22.51          | 0.42           | 0.24       |
| May 15        | 23.96          | 0.34           | 0.20       |

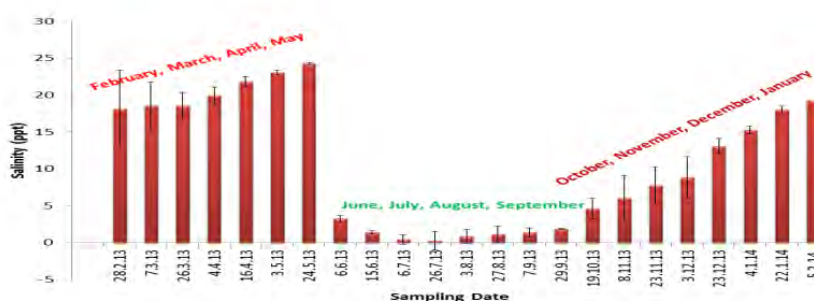


Figure 1. Seasonal salinity (ppt) level in the Pokkali field

Turbidity (NTU) level also varied significantly throughout the year (January to December). Lowest turbidity level was observed during summer (May 6.12 NTU) and maximum observed during monsoon period (June 41.50 NTU). Similarly total suspended soluble (TSS) also showed significant variation pattern throughout the year. Pearson correlation revealed (2-tailed) significant positive correlation ( $P < 0.05$  level) between the turbidity (NTU) and TSS of the Pokkali fields (Table 3).

Table 3. Results of environmental parameters in the Pokkali fields

| Parameter  | Number of observation | Mean  | SD    | Median | Mean absolute deviation | Min. Value | Max. Value | Range | Skewness | Kurtosis | Standard error |
|------------|-----------------------|-------|-------|--------|-------------------------|------------|------------|-------|----------|----------|----------------|
| Air temp   | 92                    | 31.05 | 2.32  | 31.60  | 2.67                    | 25.00      | 35.40      | 10.40 | -0.39    | -0.69    | 0.24           |
| Water temp | 92                    | 29.33 | 2.12  | 29.40  | 2.08                    | 24.10      | 33.70      | 9.60  | -0.11    | -0.54    | 0.22           |
| pH         | 92                    | 7.40  | 0.46  | 7.41   | 0.59                    | 6.54       | 8.41       | 1.87  | -0.04    | -0.82    | 0.05           |
| Salinity   | 92                    | 40.66 | 24.68 | 40.50  | 31.88                   | 1.00       | 84.00      | 83.00 | 0.08     | -1.27    | 2.57           |
| Turbidity  | 92                    | 19.18 | 11.93 | 17.57  | 9.50                    | 1.87       | 58.23      | 56.36 | 1.16     | 1.20     | 1.24           |

### Fish growth rate in Pokkali farming system

Mullet migrate to Sea during January to March periods for spawning and the fry swim towards coast during the onset of monsoon (Quignard and Fartugio, in Oven, 1981). These Mullet's fry's (collected from the wild  $3.49 \pm 0.25$  cm and weight  $481.66 \pm 57.49$  mg) were nursery reared in happas and reached fingerling size ( $6.35 \pm 0.23$  cm and  $3.54 \pm 0.16$  g) within 28 days of rearing. Mullet fingerlings reached harvestable stage ( $330.43 \pm 2.21$  g) within 270 days of post stocking in HDPE cages (Table 4).

Table 4. Length and weight increment data of mullet during nursery rearing

| Day of rearing | Length (cm)      | Weight                |
|----------------|------------------|-----------------------|
| 1              | $3.49 \pm 0.25$  | $481.66 \pm 57.49$ mg |
| 10             | $4.99 \pm 0.23$  | $1.92 \pm 0.22$ g     |
| 16             | $6.25 \pm 0.38$  | $3.16 \pm 0.35$ g     |
| 28             | $6.35 \pm 0.23$  | $3.54 \pm 0.16$ g     |
| 62             | $11.85 \pm 0.91$ | $20.92 \pm 2.97$ g    |
| 89             | $13.2 \pm 0.28$  | $25.6 \pm 2.12$ g     |
| 100            | $14.76 \pm 0.25$ | $46.83 \pm 1.44$ g    |
| 120            | $18.20 \pm 1.07$ | $67.43 \pm 2.21$ g    |

|     |            |                |
|-----|------------|----------------|
| 200 | 26.12±2.12 | 250.43±2.21 g  |
| 270 | 29.52±3.34 | 350.56±10.76 g |

Growth data of Pearl spot is furnished in Table 5. Pearl spot fingerlings (4.0 g weight with 6cm length) reached average size of 127.64 g weight and 16.36 cm within 23 weeks of farming in cage system in pokkali fields. Growth data of the pearl spot, *Etroplus suratensis* in small floating cages for eight month is given in Table 5.

Table 5. Six- month growth data of the pearl spot, *Etroplus suratensis* in small floating cages

| Duration      | Length (cm) | Weight (g) |
|---------------|-------------|------------|
| Stocking time | 6.0         | 4.0        |
| 10 weeks      | 12.9        | 52.6       |
| 14 weeks      | 13.5        | 58.6       |
| 18 weeks      | 14.4        | 69.9       |
| 21 weeks      | 14.5        | 97.6       |
| 23 weeks      | 16.36       | 127.64     |

Water quality of the field was maintained by exchanging fresh water from the creek by regulating the sluice gates.

### Harvesting

Mullets reached 350±50 g size after nine months of culture with a survival rate of 70% and harvested using gill nets and cast nets from the pokkali fields during the first week of April. Asian Sea bass reached average weight of 800 g in cages with survival rate of 80% whereas pearl spots reached 127.64 ±20 g size in cages with survival rate of 90% and harvested using scoop net as and when required (Table 6).

Table 6. Fin fish species, initial and harvest size and survival percentage in Pokkali fields

| Sl No | Species       | Average length at time of stocking | Average weight at time of stocking | Average weight at harvest | Culture period | Percentage survival |
|-------|---------------|------------------------------------|------------------------------------|---------------------------|----------------|---------------------|
| 1.    | Mullet        | 2.4 cm                             | 0.20 gm                            | 350 gm                    | 9 months       | 70                  |
| 2.    | Asian Seabass | 8.0 cm                             | 7.02 gm                            | 800 gm                    | 9 months       | 80                  |
| 3.    | Pearl spot    | 4.5 cm                             | 2.7 gm                             | 127 gm                    | 8 months       | 90                  |

### Farm gate markets

Freshly caught live pearl spot and mullet marketed through the newly established “farm gate markets” with premium price (Rs. 500/kg). This new



market received wide acceptance among fish lovers of the state due to the superior quality and taste of the live fish harvested from pokkali fields. Presently, this superior quality fish from pokkali fields are currently being mixed up in the market with low quality fish from elsewhere. This new venture has the potential to ensure safe-to eat product for the consumers at a reasonable price in chorus enhancing the income from pokkali farming towards its sustainability.

### **Cost-benefit ratio**

The fixed cost for cage culture in a 1 ha pokkali field would be Rs. 88,000/-. Since the assets can be used for 5 years, the fixed cost per year would be Rs.17,600/-. The operational cost per year comes to Rs. 90,000/-. The gross income per year would be Rs.1,90,000/- and the profit per year is Rs 83,000/-. Pokkali farmers are getting a profit of only Rs. 15,000 from paddy crop alone and Rs 50,000 only from combined paddy and shrimp cultivation from a 1 ha field. The new system of paddy-shrimp-fin fish culture ensures Rs1.3 lakhs per ha (Table 7).

Table 7. Cost economics of Integrated cage fish culture

| Item                    | Unit cost | Total No | Total no        |
|-------------------------|-----------|----------|-----------------|
| Cage unit*              | 6,000     | 10       | 60,000          |
| One Year cage Cost      |           |          | <b>12,000</b>   |
| Seed cost Asian Seabass | 30        | 500      | 15,000          |
| Seed cost Mullet        | 5         | 1,000    | 5,000           |
| Seed cost Pearl spot    | 10        | 1,000    | 1,000           |
| Feed cost               | 75        | 1,200    | 90,000          |
| Labour charges          | 600       | 100      | 60,000          |
| Other Charges           |           |          | 5,000           |
| Total Cost              |           |          | <b>1,88,000</b> |

\*The cage can be used for minimum five crops

In order to sustain the developed technologies an urgent intervention in seed production of candidate fish such as Mullet are needed, new candidate species suitable for brackish water resources has to be identified and field tested along with the present species. An intervention in development of location specific custom made machineries for land preparation and harvesting are also can contribute for the sustainable rejuvenation of this farming system.

### **Conclusion**

Pokkali is a naturally organic farming system in the coastal areas of Ernakulam district. Conventional Pokkali farming involves alternate growing of Paddy and

Shrimp in the same field. In order to reap more profit, KVK introduced a third component-fish farming and demonstrated this profitable venture in selected Pokkali fields. In this unique method, fish alone can contribute profit of INR80,000- per ha whereas paddy-shrimp farming gives only INR50,000- per ha. Subsequent to the success of this integrated farming, Fish Farmers Development Agency (FFDA), Government of Kerala has initiated a scheme - *Integrated fin fish farming in Pokkali fields*.

### **Acknowledgement**

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### How to reach CMFRI, Kochi

The institute is located 600 meters away from High Court along Abraham Madamakal Road, Ennakulam. It is around 2.5 km from Ennakulam North Railway Station and 3 km from KSRTC Bus Stand. Prepaid auto/taxi facilities are available from the station to institution.

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## About CMFRI

The Central Marine Fisheries Research Institute (CMFRI) is a government research institution under Indian Council of Agricultural Research, India. Over the past 70 years, CMFRI has displayed an unparalleled research acumen and unbridled commitment which has greatly enhanced the marine fish production and management of the fisheries sector and for the livelihood of 40 lakh fisherfolk of the country. CMFRI stands at the forefront of research in the marine capture fisheries sector in India, contributing to research into fish stock estimates, optimum fleet size, mariculture, impact of climate change on marine fisheries, marine biotechnology and biodiversity, fishery environment and fishery economics and extension.

CMFRI holds a strong foundation and achievements such as the development of National Marine Fishery Database; stock health report card of state-wise and national fish stocks; management advisories for state fisheries departments, the certification of Marine Stewardship Council for an Indian fishery resource; studies on seasonal fishing ban; marine pearl culture; artificial reefs; immense marine resources; seed production technology of marine finfish and shellfish; sea farming and coastal mariculture technologies; nutraceuticals from marine organisms; fish feeds for mariculture; genetic characterization of stocks and the digital repository - eprints@CMFRI. CMFRI is also actively involved in fisheries management and adaptation plans addressing climate change issues and impacts over the ecosystem through the Network Project on Climate Change initiated in 2006 and the National Innovations in Climate Resilient Agriculture (NICRA) implemented in 2011. There is no research organization better suited for leading India's marine fishing sector to greater heights.



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